Colorado Water Institute
Annual Technical Report
FY 2015

Introduction

Water research is more important than ever in Colorado. Whether the project explores the effects of decentralized wastewater treatment systems on water quality, optimal irrigation scheduling, household conservation patterns, the effects of wastewater reuse on turfgrass, the economics of water transfers, or historical and optimal streamflows, water is a critical issue. In a headwaters state where downstream states have a claim on every drop of water not consumed in the state, the quality and quantity of water becomes essential to every discussion of any human activity.

The Colorado Water Institute (CWI), an affiliate of Colorado State University (CSU), exists for the express purpose of focusing the water expertise of higher education on the evolving water concerns and problems being faced by Colorado citizens. We are housed on the campus of CSU but work with all public institutions of higher education in Colorado. CWI coordinates research efforts with local, state, and national agencies and organizations. State funding currently allows CWI to fund research projects at CSU, the University of Colorado, University of Northern Colorado, Metropolitan State University, and Colorado School of Mines.

Our charges this year included requests from the legislature and state and federal agencies. The Colorado Legislature continues to call upon the Colorado Water Institute to provide science-based approaches to water management. The Colorado Department of Public Health and Environment requested our assistance in engaging researchers and Extension in the public discussions of water quantity issues around the state. Water Roundtables in designated water basins elicited input from stakeholders with the goal in mind of creating an environment for water sharing arrangements in the state. In addition, CWI and the Colorado Department of Agriculture are co-chairing the State's agricultural drought impact task force.

CWI serves to connect the water expertise in Colorado's institutions of higher education to the information needs of water managers and users by fostering water research, training students, publishing reports and newsletters, and providing outreach to all water organizations and interested citizens in Colorado.

Research Program Introduction

The Colorado Water Institute funded 2 faculty research projects, 7 student research projects, and 4 internships this fiscal year. The Advisory Committee on Water Research Policy selected these projects based on the relevancy of their proposed research to current issues in Colorado.Under Section 104(b) of the Water Resources Research Act, CWI is to plan, conduct, or otherwise arrange for competent research that fosters the entry of new scientists into water resources fields, expands understanding of water and water-related phenomena (or the preliminary exploration of new ideas that address water problems), and disseminates research results to water managers and the public. The research program is open to faculty in any institution of higher education in Colorado that has demonstrated capabilities for research, information dissemination, and graduate training to resolve State and regional water and related land problems. The general criteria used for proposal evaluation included: (1) scientific merit, (2) responsiveness to RFP, (3) qualifications of investigators, (4) originality of approach, (5) budget, and (6) extent to which Colorado water managers and users are collaborating.Active NIWR projects and investigators are listed below:

Faculty Research

1. 2015CO305S Application of Remotely Sensed Data for Improved Regional and National Hydrologic Simulations - Year 2, Terri Hogue, Colorado School of Mines, $80,346 (DOI-USGS-Geological Survey)
2. 2015CO318G Trace Organic Contaminants (TOrCs) in Urban Stormwater and Performance of Urban Bioretention Systems: a Field and Modeling Study, Christopher Higgins, Colorado School of Mines, $249,960 (DOI-USGS-Geological Survey)

Student Research (Faculty advisor in parenthesis)

1. 2015CO308B Combined Influences of Hydrologic Connectivity and Nutrient Uptake on System-scale Retention, Pamela Wegener and Melissa Miller (Covino), Colorado State University, $5,000 (104b)
2. 2015CO309B Temporal Consistency of Spatial Snowpack Properties, Ben Von Thaden (Fassnacht), Colorado State University, $5,000 (104b)
3. 2015CO310B Impact of Limited Irrigation on Health and Growth of Three Ornamental Grass Species, Samuel Hagopian (Klett), Colorado State University, $5,000 (104b)
4. 2015CO311B Identifying Differential Access in Water Allocation Mechanisms: Water Rights for Oil and Gas, Karie Boone (Laituri), Colorado State University, $5,000 (104b)
5. 2015CO312B Groundwater Recharge Within the South Platte Basin, Christopher Ruybal (McCray), Colorado School of Mines, $5,000 (104b)
6. 2015CO313B Floating Wetlands Systems: Managing Aquatic Plants as a Salt and Se Sequestration Strategy, Craig Moore (Richard), Colorado Mesa University, $4,922 (104b)
7. 2015CO314B Nutrient Retention and Productivity in Rocky Mountain Streams Under Alternative Stable States, Adam Herdrich (Winkelman), Colorado State University, $5,000 (104b)

Internships

1. MOWS - Modeling of Watershed Systems NIWR-USGS Student Internship II, Roland Viger, USGS, $30,850, Melissa Valentin (Colorado School of Mines)
2. MOWS - Modeling of Watershed Systems NIWR-USGS Student Internship Program, Steve Regan, USGS, $78,509, Samuel Saxe (Colorado School of Mines), Ryan Logan (Colorado School of Mines)
3. USGS Sedimentary Transport Internship, Allen Gellis, USGS, $12,376, Lucas Nibert (Fort Lewis College)

For more information on any of these projects, contact the PI or Reagan Waskom at CWI. Special appreciation is extended to the many individuals who provided peer reviews of the project proposals.

ICIWaRM Advisory Board Meeting and Workshop

Basic Information

Title:	ICIWaRM Advisory Board Meeting and Workshop
Project Number:	2014CO304S
USGS Grant Number:	G14AP00025
Sponsoring Agency:	COE_COState
Start Date:	2/1/2014
End Date:	6/30/2015
Funding Source:	104S
Congressional District:	
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	

Publications

There are no publications.

International Center for Integrated Water Resources Management (ICIWaRM)

Partners Meeting
1-2 October 2015

SUMMARY OF MAJOR THEMES DISCUSSED AND PROPOSED ACTIONS

Venue:
Table Mountain Inn, 1310 Washington Avenue, Golden, Colorado 80401, 303-277-9898, http://www.tablemountaininn.com/

Objectives:
- Review the last 2+ years of ICIWaRM's activities, strategy, accomplishments, including related partner initiatives
- Discuss and plan new cooperative strategies and initiatives along with the funds to support them. Includes drafting pre-proposals/concept papers.

Participants:

Kathie Bailey, The U.S. National Academies and US National Commission for UNESCO
Mike Campana, Oregon State University and American Water Resources Association
Nancy Grice, Colorado State University and Colorado Water Institute
Kuolin Hsu, University of California, Irvine
Will Logan, USACE Institute for Water Resources and ICIWaRM
John Matthews, Colorado Water Institute and Alliance for Global Water Adaptation
Kevin McCray, National Ground Water Association
Rich Meganck, Oregon State University
Phu Nguyen, University of California, Irvine
Bob Pietrowsky, USACE Institute for Water Resources and ICIWaRM
Leroy Poff, Colorado State University
Aleix Serrat-Capdevila, University of Arizona
Manisha Singh, Wise Lion LLC
Reagan Waskom, Colorado State University and Colorado Water Institute

UNESCO — United Nations Educational, Scientific and Cultural Organization | ICIWaRM — International Center for Integrated Water Resources Management under the auspices of UNESCO

Primary items of discussion and proposed actions

IWRM/Nexus Master's or Certificate program

- There are still very few degree programs focused on IWRM
- USACE put together a curriculum with various universities for a master's program about a decade ago.
- AWRA had another IWRM specialty conference this summer.
- At this meeting they started talking about the relationship between IWRM and Water/Sanitation/Health (WASH). Nevada-Reno is active in this area.
- Discussed the possibility of a professional certification in Climate Change Adaptation, perhaps an AGWA certificate. There is a gap waiting to be filled here.

Action: Dig out/Rethink the USACE university-based IWRM master's concept, and see if it might be tweaked for an online version. Bob, Mike, Reagan (John, Will)

CSU and Pakistan

- CSU is part of a program led by the University of Utah plus CUNY and UNLV to engage in a USAID-Funded Partnership for Pakistani Water Center
- Partner is the Center for Advanced Studies in Water [PCASW] at the Mehran University of Engineering and Technology [MUET].
- This is a different center from the one that Pakistan has proposed for a UNESCO category 2 center (Abbottabad).

Action: Reagan will discuss with USAID if the model may be replicated in other countries.

OSU-IHE-University of Peace master's program

- Costs are about $60k/student.
- Other institutions could conceivably engage. CSU has a new peace and conflict program, as does George Mason University (Kathie).
- Still looking for a good field-based project reasonably close to OSU; AGWA has a project in Eastern Oregon that might be appropriate (John).

Action: John and Mike will discuss further.

Collaboration with UNESCO-IHE

- Fritz Holzwarth (Deputy-Director General of Ministry of Environment, Nature Protection and Nuclear Safety in Germany), Chair of the Governing Board, will become interim Rector of

UNESCO-IHE. The current Officer in Charge of IHE, Professor Dr. Stefan Uhlenbrook, will become the new Coordinator of the WWAP.

- Need to continue working on integrating GWADI products into master's theses at IHE.

Action: Put together a two pager on the concept, get endorsement by the Academic Board (Rich, Kuolin, Kristin, McClain). Rich has already sent an email to IHE to begin socializing the concept.

Action: Consider putting together a three- to seven-day G-WADI short course at IHE for alumni – what would a curriculum look like? (Rich, Kuolin, Will)

G-WADI

- PERSIANN data downloads are on track to double in 2015 compared to 2014, which had doubled from 2013. UC-Irvine is developing additional products and interfaces related to PERSIANN, including PERSIANN-CDR (climate data records) and the RainMapper app.
- Two workshops and training courses, co-sponsored by UNESCO-Bangkok, have been held on PERSIANN products in Thailand, the first through the Thai Hydrologists Association and the second in collaboration with ASEAN. A strong PERSIANN collaboration is also developing in Chile.
- University of Arizona is continuing their work through NASA SERVIR-Africa on a multi-model approach to streamflow forecasting in pilot basins in Africa.
- Student exchanges are happening – an Ethiopian student is going to spend 6 months at Arizona and a Senegalese student is going to spend 6 months at UCI.
- Various ICIWaRM partners are working on topics emphasized by G-WADI. For example, Arizona is working on a rainwater harvesting in Tucson with an EU student, and CSU is working on managed aquifer recharge (MAR) in Colorado. Mike Campana has extensive experience in geochemical and isotopic tracers. USGS personnel have been engaged in IHP's GRAPHIC (groundwater and climate) program, which is especially applicable to semi-arid regions. ICARDA is engaged in rainwater harvesting. IAH is engaged in MAR.

Action: Increase engagement of ICIWaRM partners (and potential partners) in relevant G-WADI activities (Will)

Action: Engage with John Selker of OSU on his cheap weather stations in Kenya in collaboration with TAHMO (The Trans-African HydroMeteorological Observatory; tahmo.org). (Mike, UCI)

Building our network through improved communications and publicity

- Webinars to build visibility – Mike is doing a lot of these.
- AGWA is developing
  - "outreach and capacity building for effective water management in the developing world"
  - AGWAGuide.org is a new learning platform.
  - New education partnership
- So overall, we need to consider how we could do more communications in conjunction with our partners. Will, Mike, John.

Action: Get RainMapper publicized on AGWA's networks, including ESA listserve. (John, Phu)
Action: Use GWP's partnership institutions to publicize PERSIANN and RainMapper (Mike).
Action: Get PERSIANN and RainMapper publicized through category 2 centers (Will)

- Need to make better use of the ICIWaRM logo.

Action: Will will re-send the logos around.

UNESCO HELP (Hydrologic for the Environment, Life and Policy) program

- At the global level, the program is virtually inactive. However, individual HELP basins are moving forward. ICIWaRM has funded collaboration among the North American basins.
- The Iowa-Cedar (and possibly the Willamette) river basins tie in well to USACE and ICIWaRM partner activities. In the former, USACE/IWR has had pilot projects in collaborative planning and climate change adaptation, will run a "drought tournament" in early 2016, and supported a U.Iowa researcher on hydroinformatic tools for managers. UC-Irvine researcher just published a paper on Flood Forecasting and Inundation Mapping using PERSIANN using the 2008 Cedar River flood data.

Action: Engage UC-Irvine in the Drought tournament and/or find additional synergies within USACE and elsewhere to highlight Iowa-Cedar activities as a model HELP basin.

Additional collaboration opportunities

- The International Institute for Applied Systems Analysis (IIASA). According to Kathie, the door is open for collaboration with IIASA, especially with respect to transboundary water.

Action: Reconnect ICIWaRM and IIASA either directly through David Wiberg or through the National Committee (Kathie, Bob?)

- The DOI Climate Science Centers. CSU hosts the North Central Climate Science Center. Ex-IWR scientist Janet Cushing is now Deputy Chief of the National Climate Change and Wildlife Science Center program, and Bob is on the National FACA committee for the CSCs.

Action: Contact Janet Cushing about potential opportunities for collaboration. (John, Reagan, Bob?)

- Institute of Electrical and Electronics Engineers (IEEE). Sheree Wen, of the US National Commission for UNESCO, is co-organizer of IEEE's annual Global Humanitarian Technology Conference. Seems ideal for G-WADI tools.

Action: Discuss potential engagement (in the 2016 conference, or otherwise) with Sheree (Kathie, Will).

- Additional collaboration opportunities include WMO (with USGS Emeritus Scientists Harry Lins chairing the CHy, and ex-UNESCO IHP Chair, and friend, Johannes Cullmann as Director of the WMO Climate and Water Department).

Action: Contact Lins and Cullmann about potential activities, in collaboration with UNESCO IHP staff.

Additional funding options:

- **501C3:** Discussed plusses and minuses of forming one. Question is whether there is a parent-child relationship such as NGWA (IHE, GSA…) and its foundation, or not. The former is more complicated, but keeps better control over the direction. IRS reporting can be relatively painless if gifts are all below ~500k. But articles of incorporation are key, and even more important is to be 100% clear about the foundation's purpose. Another potential model would be the "Friends of IIASA" model, which enables people in the US to contribute to IIASA while getting the tax deduction.

Action: Continue looking at options (Gene, Rich, Mike(?))

- Barbara Chow, Program Director, Education Program of Hewlett Foundation, is on the USNC-UNESCO. Kathie asked her for any ideas for collaboration, but she said we were out of her area of expertise.

Action: Get in touch with Barbara about either Amb. Nix-Hines' education project or to find a contact in Hewlett's Global Development and Population Program for a G-WADI project (Kathie, Will).

Action: Also look at Rockefeller (which one?) for G-WADI products; they have funded data-related projects (John, Will).

- The director of NSF's Environmental Engineering program is Bill Cooper, who while at UCI sponsored the first and only UNESCO water conference of the "modern era" in the US.
- The USAID-NSF Partnerships for Enhanced Engagement in Research (PEER) Program has a new call out, with pre-proposals due January 15, 2016.

Action: Work with international partners to submit various pre-proposals.

- John has been involved in Green Bonds for funding water projects.

Action: Investigate possibilities for "AGWA-certified Green Bonds", for example, or otherwise help with developing a certification process (who's the lead?).

News from American Water Resources Association (& National Ground Water Association)

- "Groundwater Visibility Initiative: Integrating Groundwater and Surface Water Management" Workshop. Denver, April 2016, covering areas such as Groundwater-Surface Water interactions and conjunctive use of groundwater and surface water. It's an add-on to NGWA's groundwater summit.

Miscellaneous

- The UNESCO category 2 center in Frutal, Minas Gerais, Brazil, which has engaged Rich Meganck in various roles over the past 5 years, is in a complicated political situation right now and has only four employees at the moment. We hope that the situation is resolved in the near future. Rich will continue to engage, but otherwise no action.
- There will be a fair number of ICIWaRM partners at AGU December 14-18.

Action: Have a meeting of as many ICIWaRM partners as possible there (Will, Jerad, UC-Irvine).

Application of Remotely Sensed Data for Improved Regional and National Hydrologic Simulations

Basic Information

Title:	Application of Remotely Sensed Data for Improved Regional and National Hydrologic Simulations
Project Number:	2014CO305S
USGS Grant Number:	G14AC00267
Sponsoring Agency:	USGS
Start Date:	7/18/2014
End Date:	3/31/2015
Funding Source:	104S
Congressional District:	
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	

Publications

There are no publications.

Unsolicited Cooperative Agreement Proposal to the
USGS Colorado Water Resource Research Institute

Extension to current agreement: Application of Remotely Sensed Data for Improved Regional and National Hydrologic Simulations

Lead PI: Dr. Terri Hogue
Associate Professor and Vice Chair
Civil and Environmental Engineering
Colorado School of Mines
1500 Illinois Street
Golden, CO 80401

Research Associate: Paul Micheletty

Performance Period: April 1, 2015 through January 31, 2016

Requested Funding: $80,346

1. Introduction

The overarching goal of this proposal extension is to continue to improve hydrologic modeling of the contiguous United States (CONUS) through integration of remotely sensed data products (RSDPs) from the USGS EROS center, as well as those being developed through research led by PI Dr. Terri Hogue, Associate Professor at the Colorado School of Mines. The proposed research is to improve estimates of growing season and land cover based remotely sensed phenology products for use with the Precipitation Runoff Modeling System (PRMS). The Hogue research group (http://inside.mines.edu/~thogue/) will facilitate this research in cooperation with the USGS Modeling of Watershed Systems (MoWS) group (http://wwwbrr.cr.usgs.gov/projects/SW_MoWS/), the developers of PRMS. The Hogue research group has extensive research, development, and application experience with RSDPs and hydrologic modeling. This experience includes analysis of vegetation and land-surface temperature (Kim and Hogue, 2012b), vegetation and snow to evaluate post-fire recovery hydrologic response and recovery (Kinoshita and Hogue, 2011; Micheletty et al., 2014), potential evapotranspiration (Kim and Hogue, 2008; and Muhammad et al., 2014), potential evapotranspiration input to a hydrologic simulation code (Bowman et al., 2014 and Spies et al., 2014), actual evapotranspiration (Kim and Hogue, 2013), and soil moisture estimates (Kim and Hogue, 2012b).

The proposed research presents a unique opportunity to facilitate research through the Colorado Water Resources Research Institute and the USGS National Research Program to explore the application of available RSDPs and their use in PRMS. The particular application of PRMS is the National Hydrologic Model (NHM) that is delineated based on aggregated NHDPlus (http://www.horizon-systems.com/nhdplus/) catchments for the CONUS. This project proposes to integrate RSDPs in three basic ways: (1) to improve default model parameterizations, (2) produce additional modules, and (3) to be used as validation datasets.

2. Proposed Tasks

2.1 Previously proposed tasks: Integrating a RSDP growing season

The first phase of work proposed for this project previously included integrating the vegetation phenology product developed at the USGS EROS Center (http://phenology.cr.usgs.gov/) to derive growing season (i.e. period of active transpiration) parameters for use in the NHM. This phase was successfully completed by defining two RSDP derived growing season parameter sets (static and dynamic) for each hydrologic response unit (~110,000) in the NHM for water years 1990- 2010. The static RSDP growing season is derived for each HRU by calculating long-term (1990-2010) average annual growing season dates which are then fixed for the deration of the simulation period, while the dynamic parameter set defines a growing season for each individual year. Using the NHM, modeled hydrologic outputs were produced using default model parameters and the two RSDP derived parameter sets. Spatial and temporal anomalies of model outputs such as actual evapotranspiration (AET), surface runoff, interflow, and groundwater flow (baseflow) were then compared between model runs with the default parameter set and the RSDP dataset (Figure 1). Results show anomalies in AET and the components of flow vary geographically, and are correlated to land cover type. The largest anomalies for this year are apparent in the northeastern regions and Rocky Mountain West, where the baseline model produces more AET and less baseflow compared to the model ran with the RSP growing season. Annual differences in AET can reach up 10 inches in certain HRUs which may have significant implications for the annual water balance in those areas.

After an analysis of spatial and temporal anomalies in simulated flow, it was decided to incorporate the static RSDP derived growing season into the NHM as a replacement for the default temperature index.

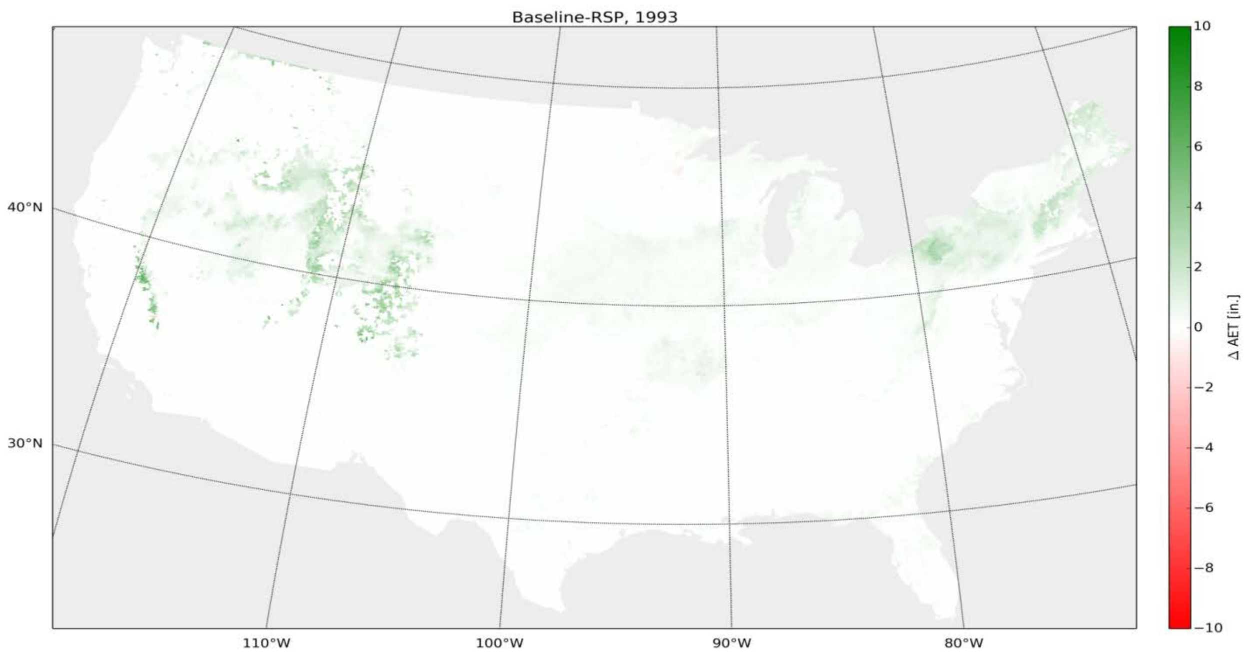


Figure 1. Anomaly map of modeled annual AET (1993). Anomalies here are displayed as differences in baseline (default growing season module) model output minus model output with static RSDP growing season. *Note that all other model parameters are identical.

2.2 Future Work

Proposed work for this proposal extension will focus on two new objectives: (1) evaluation of model performance using new RSDP growing season parameters compared to observed datasets, and (2) development of a Leaf Area Index (LAI) module. Currently, there is an effort within the Modeling of Watershed System (MoWS) research group to perform a national model calibration starting with roughly 1800 USGS gages that have long periods of record and that are relatively undisturbed. Once the model is calibrated, a more rigorous analysis of model performance using the new RSDP derived parameter sets can be executed. The spatial analysis performed previously across the CONUS delineated areas sensitive to the growing season and will be used to guide our basin selection for this more quantitative assessment. The model results will be evaluated against the following observational datasets: (1) USGS streamflow, and (2) actual evapotranspiration produced from remote sensing products MOD16 and the operational Simplified Surface Energy Balance (SSEBop). Using remote sensing products as validation datasets provides us with the ability to evaluate the results spatially as well as temporally. Model results will be evaluated using a suite of typical objective functions such as: Nash-Sutcliffe efficiency (NSE), root mean squared error (RMSE), bias and correlation (R) at daily (when available), monthly, and annual time scales.

Additional to the RSDP defined growing season parameter set, we propose developing a simple LAI module. From our previous analysis of the growing season, it was apparent that the way the PRMS models vegetation processes such as: interception, transpiration, storage, etc. could be improved through the use of an LAI module. LAI is the ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows. LAI is a dimensionless value, typically ranging from 0 for bare ground to 6 for a dense forest. Transpiration varies according to physiological (plant conductance) and structural properties (Granier et al., 2000), while interception varies according to structural properties of the vegetation, (Muzylo et al., 2009) both of which can be estimated as function of LAI. In the simplest case, plant transpiration can be simulated as a linear function of potential evapotranspiration and LAI. Many hydrologic models, including the Soil Water Assessment Tool (SWAT), Variable Infiltration Capacity (VIC) model, Community Land Model (CLM), etc. utilize LAI to some extent. However, all of these models calculate LAI based on vegetation type and temperature. We will attempt to eliminate this step by defining LAI based on RSDP estimates. This allows us to explicitly and dynamically define LAI in space and time. There are LAI products available in multiple satellite platforms including: the Moderate Resolution Imaging Spectroradiometer (MODIS; MOD15), and the Advanced Very High Resolution Radiometer (AVHRR) which will be investigated for use in the second phase of this project.

Improving the vegetation related parameters within the NHM should improve model performance and reliability, especially when modeling drought years when water availability, demand, and usage are so critical.

3. Deliverables / Timeline

Deliverables under this cooperative agreement extension grant will include:

- 1 peer-reviewed publication of the integration of RSDP defined growing season
- LAI Module

Timeline	**Year 1 (10 Month Period)**									
	1	2	3	4	5	6	7	8	9	
1. Perform NHM Calibration (in cooperation with other MoWS researchers)										
Develop calibration routine	•	•								
Perform calibration		•	•	•						
2. Assess Model Performance										
Evaluate model performance based on USGS Streamflow				•	•					
Evaluate model performance based on RSDP derived AET				•	•	•				
3. Development of simple LAI Module										
Acquire LAI RSPDs	•				•					
Develop LAI Module using previously published relationships for LAI, storage, interception, and transpiration					•	•	•	•	•	•
4. Communication of the results										
Publication of journal article								•	•	•

References

Granier, A., Loustau, D., and Bréda, N., 2000: A generic model of forest canopy conductance dependent on climate, soil water availability and leaf area index, *Ann. For. Sci*., 57, 755–765.

Kim, J. and T.S. Hogue, 2008: Evaluation of a MODIS-based Potential Evapotranspiration Product at the Point-scale, *Journal of Hydrometeorology*, 9, 444-460.

Kinoshita, A.M, and T.S. Hogue, 2011: Spatial and Temporal Controls on Post-fire Hydrologic Recovery in Southern California Watersheds, *Catena*, 87, 240-252.

Kim, J., and T.S. Hogue, 2012a: Improving Spatial Soil Moisture Representation through Integration of AMSR-E and Visible and Near-infrared MODIS Products, *IEEE Transactions on Geoscience and Remote Sensing*, 50(2), 446-460.

Kim, J., and T.S. Hogue, 2012b: Evaluation and sensitivity testing of a coupled Landsat-MODIS downscaling method for land surface temperature and vegetation indices in semi-arid regions, *Journal of Applied Remote Sensing*, 6(1), 063569-1-17.

Kim, J., and T.S. Hogue, 2013: Evaluation of a MODIS triangle-based evapotranspiration algorithm for semi-arid regions, *Journal of Applied Remote Sensing*, 7(1), doi: 10.1117/1.JRS.7.073493

Bowman. A.L., K.J. Franz, T.S. Hogue, and A.M. Kinoshita, 2013: MODIS-based potential evapotranspiration demand curves for the Sacramento Soil Moisture Accounting model, *Journal of Hydrologic Engineering (in review)*

Spies, R., K. Franz, and T.S. Hogue, 2014: Distributed hydrologic modeling using satellite-derived potential evapotranspiration, *Journal of Hydrometeorology (in review)*

Micheletty, P.D., A.M. Kinoshita, and T.S. Hogue, 2014: Application of MODIS snow cover products: wildfire impacts on snow and melt in the Sierra Nevada, Hydrol. Earth Syst. Sci., 18, 4601-4615, doi:10.5194/hess-18-4601-2014.

Muhammad, B., T. S. Hogue, K. J. Franz and A. Kinoshita, 2014: Satellite based potential evapotranspiration estimates in the Colorado River Basin *(in prep)*.

Muzylo, A., Llorens, P., Valente, F., Keizer, J. J., Domingo, F., and Gash, J. H. C., 2009: A review of rainfall interception modelling, *J. Hydrol*., 370, 191–206, doi:10.1016/j.jhydrol.2009.02.058.

Proposal Budget

PROPOSED BUDGET
April 1, 2015 - January 31, 2016 (10 months)

			Amount	Total
A.	SALARIES AND WAGES			
	1.	Terri Hogue, PI - 2 summer days	$1,168	
	2.	Research Faculty @ $25/hour for 40 hrs/week for 43 weeks	43,000	
		Subtotal		$44,169
B.	FRINGE BENEFITS			
	1.	37.7% of A1	$440	
	2.	18.5% of A2	7,955	
		Subtotal		$8,395
C.	OTHER DIRECT COSTS			
	1.	AGU travel		$1,000
D.	TOTAL DIRECT COSTS			$53,564
E.	INDIRECT COSTS (50% of D)			26,782
F.	**TOTAL AMOUNT REQUESTED**			**$80,346**

Combined Influences of Hydrologic Connectivity and Nutrient Uptake on System-scale Retention

Basic Information

Title:	Combined Influences of Hydrologic Connectivity and Nutrient Uptake on System-scale Retention
Project Number:	2015CO308B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Water Quality
Focus Category:	Geomorphological Processes, Geochemical Processes, Hydrogeochemistry
Descriptors:	None
Principal Investigators:	Tim Covino

Publications

There are no publications.

Final Report for Project

Title: Combined Influences of Hydrologic Connectivity and Nutrient Uptake on System-Scale Retention

Investigator(s): Pam Wegener, MS Candidate, Watershed Science and Melissa Miller, BS Student, Watershed Science, Ecosystem Science and Sustainability, Colorado State University

Advisors: Dr. Tim Covino, Ecosystem Science and Sustainability, Colorado State University

---

Introduction

From May-September 2015, researchers at Colorado State University's Ecosystem Science and Sustainability Department conducted fieldwork in North Saint Vrain Creek in Rocky Mountain National Park, Colorado. The purpose of this study was to better understand how the strength of hydrologic connectivity (exchange of water, sediment, and nutrients) between the river and the floodplain influenced stream ecosystem metabolism, or the rate in which organisms produce and consume energy in fluvial systems. In wet valley meadow systems, river-floodplain hydrologic connectivity controls the degree of exchange between the main channel and floodplain surface water-bodies (e.g., side-channels and ponds), and is therefore important for connecting nutrient sources and sinks, and in turn, enhancing stream ecosystem metabolism. For example, a floodplain surface water-body such as a side-channel may be a safe refuge for algae, which would be easily washed away by the faster moving water of the main channel. Such algae may require nutrients transported from the main channel for biologic processes and growth. After algae die, algal detritus can return to the main channel and become an important downstream energy resource for microbial respiration. Stream ecosystem metabolism describes the rate in which organic matter cycles through various compartments, and can serve as an indicator of stream health.

An experiment was designed to test the hydrologic mechanisms that optimize stream ecosystem metabolism in the Wild Basin Watershed, an 88-km^2 watershed in Rocky Mountain National Park, Colorado. The Wild Basin Watershed is an ideal location to study the influence of river-floodplain (lateral) hydrologic connectivity on stream ecosystem metabolism because it consists of two reach segments with dramatically contrasting hydrologic responses to snowmelt: an unconfined multi-thread wet valley meadow, and a valley-confined single-thread channel. The North Saint Vrain Creek drains the Wild Basin Watershed and is dominated by seasonal snowmelt; streamflow rises abruptly in late May during peak snowmelt, and then decreases back to baseflow conditions by September. During high flows, the unconfined segment can dissipate flow laterally via the floodplain, whereas the confined segment is valley-constrained. As a result, the confined segment has less variability in river-floodplain hydrologic exchanges relative to the unconfined segment from high to low flows.

The goals of the research study were two-fold. First, the research focused on quantifying = the timing and magnitude of water and dissolved organic carbon (DOC) fluxes in the unconfined versus the confined segment to evaluate the relative retention/transport potentials for each landscape type. DOC is an important energy resource for microbial respiration, and as such, DOC retention is strongly related to stream ecosystem metabolism. Second, the research study focused on the influence of lateral hydrologic connectivity on stream ecosystem metabolism by comparing metabolism rates measured at the outflow of the unconfined segment versus the outflow of the confined segment. Additionally, metabolism rates were measured in two floodplain surface water-bodies in the unconfined segment to evaluate the contributions of floodplain water-bodies to stream ecosystem metabolism from high to low flows.

Methods

In March 2015, prior to snowmelt, a network of instrumentation were set up in the main channel at the inflows and outflows of the unconfined and confined segments, and in six side-channels and seven ponds in the floodplain. The monitoring sites consisted of automatic sensors that continuously recorded water height (stage), colored dissolved organic matter (CDOM), and dissolved oxygen (DO) concentrations. Each site was visited approximately weekly to download the data, calibrate the instruments, and collect grab samples which were field-filtered and sent to the Fort Collins Rocky Mountain Research Lab to analyze for nutrients and major cations and anions.

In order to compare the relative water and DOC retention/transport potentials for the unconfined versus the confined segment, streamflow and DOC data were needed at the inflows and outflows of each segment. Empirical relationships between stage and streamflow were created to transform continuous (15 minutes) stage to continuous flow at each site. Weekly measurements of flow were gathered using the standard U.S, Geological Survey velocity-area method, which involves stretching measuring tape across the width of the stream and taking stream velocity measurements at various increments along the channel transect. Daily water fluxes and balances from flow data were calculated along with unconfined and confined segment water balances as the difference between water fluxes at the outflow and inflow of each segment. A similar approach was used to calculate unconfined and confined segment DOC fluxes and balances. First, an empirical relationship was developed between CDOM and DOC concentrations analyzed from grab samples. Then, that relationship was used to transform continuous CDOM to continuous DOC, and used those data in conjunction with flow to calculate daily DOC fluxes and balances for the segments.

The timing and magnitude of normalized stage fluctuations between floodplain side-channels/ponds and the main channel were compared to evaluate the strength of lateral hydrologic connectivity across flow regimes. This method assumes that the more hydrologically connected the side-channels and ponds are with the main channel, the more in-phase the stage fluctuations are between those water-bodies and the main channel. The relative connectivity values for each of the floodplain water-bodies were averaged to categorize periods of “high” and “low” connectivity. Lateral hydrologic connectivity in the unconfined segment was strongly related to flow, with high connectivity occurring during peak flows from around June 10^{th} – July 10^{th}, 2015.

The ecosystem metabolism rates were calculated at the outflows of the unconfined and confined segments and two floodplain surface water-bodies - a side-channel and a pond – using an open-channel, single-station, diurnal DO change approach. Ecosystem metabolism rates include primary productivity (the autotrophic production of organic carbon and oxygen) and respiration (the auto- and heterotrophic consumption of organic carbon and oxygen). During daylight hours, primary productivity releases oxygen to the water, and stream DO concentrations increases. During dark hours, primary productivity essentially shuts down, respiration is the dominant metabolic process and consumes oxygen from the water, and stream DO concentrations decrease. The DO change approach essentially calculates metabolism as a function of the magnitude of diurnal DO change, in which greater changes in diurnal DO concentrations are associated with higher metabolism rates.

Results & Discussion

The unconfined segment buffered water and DOC fluxes relative to the confined segment. The unconfined segment transported a net total of 0.12 m^3 ha^{-1} of water and 0.08 g ha^{-1} of DOC per meter downstream, whereas the confined segment transported a total of 1.9 m^3 ha^{-1} of water and 7.2 g ha^{-1} of DOC per meter downstream during the monitoring period. While the confined segment was a consistent source of water and DOC, the unconfined segment displayed variable source/sink dynamics, transporting water and DOC during low flows and storing water and DOC during high flows.

The strength of lateral hydrologic connectivity was strongly related to stream ecosystem metabolism at the confined and unconfined segments, and in the floodplain water-bodies where DO was monitored. The floodplain water-bodies had higher metabolism rates following hydrologic disconnection with the main channel, which we attribute to increased water residence times that extended the duration of contact between microbes and their substrate and facilitated organic matter processing. Metabolism rates measured at the outflow of the confined segment were consistently lower than rates measured at the outflow of the unconfined segment, which were more variable and peaked at intermediate levels of connectivity. It is believed that the confined segment had relatively low and consistent metabolism rates from high to low flows because it was valley constrained. As such, the confined segment did not develop floodplain surface water-bodies with high variability in processing rates as a function of streamflow. Lastly, it is believed that metabolism rates at the outflow of the unconfined segment – which peaked at intermediate levels of connectivity – were optimized at the trade-off between high processing efficiencies in floodplain water-bodies and sufficient levels of hydrologic exchange between those water-bodies and the main channel. During high flows, energy resources such as DOC are stored in unconfined segment floodplain water-bodies and are then utilized when flows decline, residence times increase, and processing rates are optimized. This in turn suggests that intermittent connectivity is crucial to stream ecosystem metabolism in riparian wetlands.

The ability of unconfined wet valley systems to retain DOC (an important energy resource) relative to other landscape types is key to the disproportionate contribution of these landscape features to biogeochemical processing in river networks. However, there is a surprising lack of research on how stream ecosystem metabolism –an integrative measure of nutrient and organic matter processing in fluvial systems - responds to seasonal changes in the strength of river-floodplain hydrologic connectivity. As a consequence, constructed wetlands, for example, are commonly built using compacted clay substrate and periphery berms that result in decreased hydrologic connectivity relative to natural wetlands. It is suggested that intermittent river-floodplain hydrologic connectivity can optimize stream ecosystem metabolism, and as such, is an important mechanism to consider in wetland construction/mitigation practices that seek to optimize nutrient and organic matter processing and associated stream ecosystem health.

Temporal Consistency of Spatial Snowpack Properties

Basic Information

Title:	Temporal Consistency of Spatial Snowpack Properties
Project Number:	2015CO309B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Climate and Hydrologic Processes
Focus Category:	Water Quantity, None, None
Descriptors:	None
Principal Investigators:	Steven Fassnacht

Publications

There are no publications.

Final Report for Project

Title: Snowpack Accumulation Patterns Across the Southern Rocky Mountains

Investigator: Benjamin C. Von Thaden, MS Candidate, Watershed Science, Colorado State University

Advisor: Dr. Steven R. Fassnacht, Ecosystem Science and Sustainability, Colorado State University

Introduction

Understanding patterns and variability in spatial snow distribution is critical in determining the timing, magnitude, and inter-annual consistency of snowmelt runoff and are crucial inputs to snowmelt hydrology models. Year-to-year patterns are known to exist in snowpack properties. Relatively few studies have attempted to quantify such patterns, and no studies were found that quantify snowpack patterns at the modeling scale (the scale of the Southern Rocky Mountains). This study used variogram analysis with snow water equivalent (SWE) data at 90 long-term Natural Resources Conservation Service Snow Telemetry (SNOTEL) stations located across the southern Rocky Mountains to examine the consistency and spatial extent of snowpack accumulation patterns. This work used the hypothesis that there is a physical distance between SNOTEL stations beyond which snow accumulation patterns in the southern Rocky Mountains are less correlated. To examine this hypothesis, the following objectives were addressed: (1) determine how SWE varies for individual dates in the accumulation season, (2) determine the consistency of snowpack accumulation patterns over time for all pairs of SNOTEL stations, (3) if the patterns are consistent, determine the spatial extent of this consistency, and (4) define if subsets of stations pairs can better explain spatial accumulation patterns.

Study Area

The Southern Rocky Mountains span from the Laramie Range in southern Wyoming, through Colorado, and into northern New Mexico near Santa Fe. Most of the long term SNOTEL stations in the Southern Rocky Mountains are at elevations from 2300 to 3500 meters. The SNOTEL station with the deepest mean peak SWE is Tower (1324 mm) located on Buffalo Pass near Steamboat Springs, Colorado, while the station with the shallowest mean peak SWE is Copeland Lake (144 mm) located in Rocky Mountain National Park near Allenspark, Colorado. The largest distance between SNOTEL pairs is 757 km. Many of the stations started operating in the late 1970s; 32 years of daily data, starting in 1982 were used in this analysis.

Methods

Variograms are plots of the variance of all data from station within a range of distances apart from one another versus that distance, called the lag-distance. These were constructed through pair-wise analysis in which each long-term SNOTEL station was compared among all other 89 SNOTEL stations for the period of record. The main feature of interest in the variograms is the scale break. A scale break occurs at a lag distance where a substantial change in the driving process exists and occurs when there is a notable change (increase in this case) in variance beyond a given lag distance. Initially two variograms were constructed from individual day SWE values based on (1) four dates in separate accumulation years from a high, low and two average accumulation years, and (2) four dates in the same accumulation year. The individual day SWE variograms were used to examine how SWE varies for individual dates in the accumulation season.

Starting with one SNOTEL pair, the first step was to identify the concurrent period of accumulation for the first year on record. This concurrent period of accumulation begins when both SNOTEL stations have begun accumulating and ends as soon as one of the SNOTEL stations reaches its' maximum annual SWE. The SNOTEL station with the larger maximum mean SWE is set as the independent variable and the other is set as the dependent, the relative accumulation slope is computed from SWE values on the same day for the entire accumulation season. Next, the variance is computed for all station pairs within a range of lag distances, herein using 20 kilometer intervals, and the variogram is plotted. Additionally, the data were subset into SNOTEL station pairs based on their latitude and by the land cover type.

Results

For the individual day SWE variograms, no scale breaks were found, although consistent patterns in the SWE variance were found through the extent on all four dates on both variograms. Further, the amount of variability in SWE variance was found to be a function of the magnitude of SWE: the higher the average SWE across all stations, the higher the variance.

Three power functions were fitted to the entire relative accumulative data dividing it by two scale breaks occurring at approximately 100 and 340 kilometers (*Figure 1*). Note, that the variogram is in log-log space in order to easily display all of the data, and the fitted functions are power functions that appear linear in log-log space, and aid in visualizing scale breaks.

The first subset analysis divided station pairs into a north and south zones about the parallel 38°45'N. This approach was chosen based on previous studies that found a snowpack-based divide in the climatology measured at SNOTEL stations within the study region. No scale breaks were found in this variogram, although the south zone stations exhibited a greater increase in variance with distance, i.e., steeper relative accumulation slope than that of the north zone stations. This illustrates the differing climatologies in the north and south zones. The second subset analysis divided station pairs by land cover type at each station in the pair (evergreen, non-evergreen, or a mixture of both types), and exhibited scale breaks in all three land cover pairings at approximately 140 kilometers.

Conclusion

The relative accumulation rate in the Southern Rocky Mountains was found to be constant up until 100 kilometers, after which it displays a steeper but constant (almost linear) increase. Beyond 340 kilometers the relative accumulation rate shows a steeper (cubic) increase. The location-based variogram showed the most variability in relative accumulation rates to occur in the south zone station pairs. While the land cover-based variogram exhibited scale breaks around 140 kilometers for all three land cover types, land cover showed little effect on relative accumulation rates. This approach provides a new method to analyze snowpack accumulation. The scale breaks can be used to inform snow accumulation modeling and sampling strategies at larger scales, as well as inform the placement and spacing of future snowpack measurement stations.

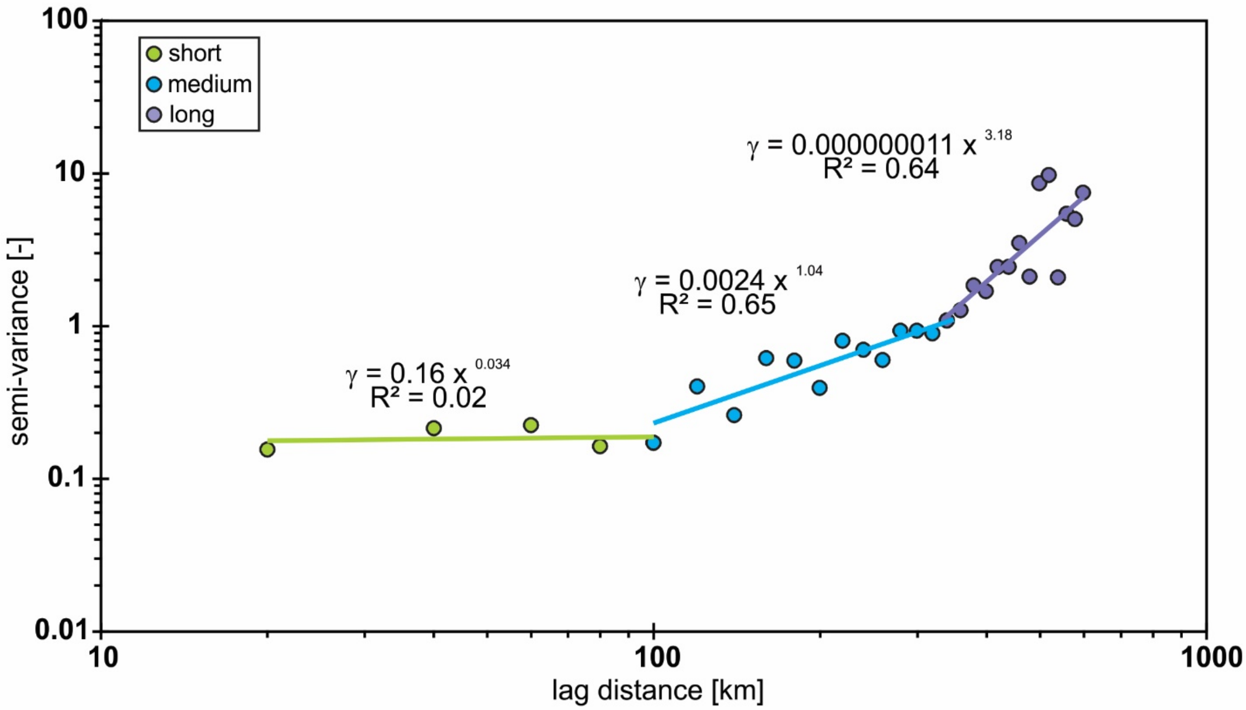


Figure 1: Variogram plot of all station pairs on log-log axes with the power functions fitted to data bins of three lag sections, separated by scale breaks.

Picture 1: Ben Von Thaden and Steven Fassnacht measure snow depths and record GPS coordinates during the 2014 Little South Fork of the Cache la Poudre Snow Survey. Photograph by Bill Cotton

Picture 2: Ben Von Thaden and Steven Fassnacht measure snow depths and record GPS coordinates during the 2014 Little South Fork of the Cache la Poudre Snow Survey. Photograph by Bill Cotton

Picture 3: Ben Von Thaden explores snow distribution at Montgomery Bowl near the Joe Wright SNOTEL and Deadman Hill SNOTEL in 2015. Photograph by Steven Fassnacht.

Impact of Limited Irrigation on Health and Growth of Three Ornamental Grass Species

Basic Information

Title:	Impact of Limited Irrigation on Health and Growth of Three Ornamental Grass Species
Project Number:	2015CO310B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Biological Sciences
Focus Category:	Water Use, Drought, Irrigation
Descriptors:	None
Principal Investigators:	James E Klett

Publications

There are no publications.

Final Report for Project

Title: Impact of Limited Irrigation on Health of Three Ornamental Grass Specie

Investigator(s): Sam Hagopian, MS Student, Horticulture/ Horticulture Operations, Colorado State University

Advisor(s): Dr. Jim Klett, Horticulture and Landscape Architecture, Colorado State University

---

Introduction

Water is one of the most valuable and limited resources in the world, and water availability is slowly decreasing. Much of the information available about standard landscape watering procedures is not research based, and is instead based on general observations and age old practices. To improve the research, finding exact water use of specific landscape species is extremely valuable in terms of water savings for homeowners and industry personnel. It is important to find precise irrigation needs of a few species of ornamental grasses, and research the limits to which these plants can survive around those needs. Discovering the stress range in which a plant will survive, grow, thrive, or wilt and fail to recover is of critical importance and has the potential to represent a large range of related species. As ornamental grasses become more important components of urban landscapes and large-scale nurseries, it is imperative that their water needs are better understood and landscape characteristics are scientifically researched.

The purpose of this study was to assess ornamental quality and plant stress of three ornamental grass species under four different irrigation regimes, quantify a feasible irrigation standard at which ornamental grasses should be watered, and identify the pattern of water use within the soil profile to understand rooting behavior of these grasses. More generally, it is important to understand if deficit irrigation is feasible with ornamental grasses. This research has large applications to Colorado in knowing if deficit irrigation is feasible once periods of drought are introduced. While previous research has touched on growing these grasses, this study serves as a pioneer in linking ornamental quality with physiological stress and growth, providing a baseline for the levels of stress these plants can endure while maintaining good aesthetic quality. The most applicable aspect of this research lies in quantifying the actual Evapotranspiration (ET) that these plants undergo. Industry personnel and researchers base a majority of irrigation practices on ET, and this is why effective quantification of ET is a key aspect of precise irrigation management (Irmak, 2009).

Methods

Two studies were performed, termed the Water Use Study and Lysimeter Study. All measurements for both studies were taken throughout the 2014-2015 growing seasons. The water use study examined three species of ornamental grasses: Panicum Virgatum ‘Rotstrahlbusch’ (Rotstrahlbusch Switchgrass), Schizachyrium Scoparium ‘Blaze’ (Blaze Little Bluestem), and Calamgrostis Brachytricha (Korean Feather Reed Grass). The study consisted of four treatments; 0%, 25%, 50%, and

100% Bluegrass ET (ET_o). Irrigation treatments were calculated and applied once a week.

Two generalized categories of data were collected, plant stress, and ornamental quality. Plant stress parameters included: predawn water potential (Ψ), infrared canopy temperature, percent water content in the soil profile, and dry weight. Plant ornamental quality parameters included: height, width, circumference, green-up date, flowering date, floral impact, landscape impact, overall habit/lodging, color, self-seeding, and representative photographs.

The lysimeter study examined one species of ornamental grass: Schizachyrium Scoparium 'Blaze', which were placed field in a pot-in-pot system. The three treatments applied were 25%, 50%, and 100% of actual plant ET (ET_s). The same plant stress and aesthetic measurements were chronicled in the lysimeter study as in the water use study. In addition, four dry down periods were conducted each year. This consisted of providing each treatment with its relative level of irrigation, and then allowing plants to dry down to critical stress levels (periods of drought). During dry down periods, entire pot and plant weight were measured on a daily basis, recording weight loss, and in turn ET_s. To measure plant stress during these periods, water potential readings were taken daily.

Results

Water Use Study - Stress Measurements

Water potential for both seasons showed the 0% treatment was significantly more stressed than the other three treatments (Figure 1). Infrared canopy temperature showed the same trend, with the 0% treatment being significantly more stressed than the other three treatments.

Water Use Study - Landscape Measurements

End of season height showed differences between treatments for each species. While results varied for each species, the trend of 0% being significantly smaller held true for all three species (Figure 2). End of season circumference followed the same trend, in the 0% being significantly smaller than all other three treatments. Floral impact, landscape impact, overall habit/lodging, and self-seeding showed that 0% held less aesthetic value than all other treatments. Each landscape category had slight differences between treatments for the 2014 and 2015 seasons, however these differences are considered negligible as all plants in the 25%, 50%, and 100% treatments were considered suitable for use in the landscape trade (Figure 3).

Water Use Study – Rooting Behavior: In order to extract the most detailed information, both year and species were combined in order to analyze by treatment and by depth. Research indicates that ornamental grasses cease accessing significant portions of water at a depth of between 20cm-30cm from the soil surface.

Lysimeter Study – Evapotranspiration (ET): During the first two dry downs of 2014 and 2015 seasons there was no difference in ET between treatments (Figure 4). These dry downs took place in July and early August and lasted anywhere from 5 to 13 days (depending on local weather). This indicates that as the plants were growing, their initial foliage early in the growing season and increasing in both height and width, they use the same amount of water regardless of treatment. The more interesting data comes during the third and fourth dry downs in mid-August and September during both seasons. During the third dry down in both 2014 and 2015, the 25% and 50% treatments used less water than the 100% treatment (Figure 5). During the fourth dry down in both 2014 and 2015, the 25% treatment used significantly less water than the 50% and 100% treatments, and the 50% treatment used significantly less water than the 100% treatment (Figure 5). This confirms the hypothesis that during each season, as the plants gain circumference, begin flowering, and acquire fall color, the plants receiving deficit irrigation were using less water. Overall, the 25% treatment used 50-60% of the water used by the 100% treatment. This indicates that within a few months, Schizachyrium Scoparium 'Blaze' is capable of adapting to a lower water regiment, and effectively budget the water needed for proper survival.

Lysimeter Study - Stress Measurements

During the first two dry downs of 2014 and 2015 there was no difference in stress between treatments. The third dry down of 2014 and 2015 (mid-August) results in 25% and 50% being more stressed than 100% (Figure 6). The fourth dry down of 2014 and 2015 (late August/early September) results in the 25% being more stressed than the 50% and 100% treatments, and the 50% treatment being more stressed than the 100% treatment (Figure 6). This suggests that the less irrigation a plant receives, the more physiologically stressed they are than their fully irrigated counterparts. The one commonality to the final two dry down periods is that the 25% treatment was always significantly more stressed once the plants reach 5 to 7 days without water.

Lysimeter Study – Visual Ratings

There were no significant differences for height, width, circumference, floral impact, landscape impact, or overall habit between treatments for either the 2014 or 2015 season.

Discussion

Water Use Study

In regards to measurements of physiological stress, plant size, and aesthetic value for all three species, the 0% treatment was significantly more stressed while the remaining treatments are equally stressed. This indicates that plants grown with a 25% irrigation regiment are equally unstressed and hold the same aesthetic/landscape values as a plant receiving the 100% irrigation. Allowing for these grasses to be irrigated with 25% bluegrass ET allows for 75% water savings as well as plants that are of equal health and landscape quality as those irrigated with 100%. A 0% irrigation regimen was determined not to be a feasible option, resulting in plants not suitable for the landscape trade.

Water Use Study – Rooting Behavior

Ornamental grasses access a majority of their water between 20cm-30cm. Since this is a shallow depth, which is easily dried out by common earth elements (wind, erosion, etc.), it would seem more important to get a widely distributed irrigation pattern around these grasses as opposed to a deeply distributed pattern. It is also likely that applying mulch to the base of these grasses would aid in longer water retention.

Lysimeter Study: The most important conclusion comes from coupling the concepts of ET and water potentials. The ET data generated indicates that as the growing season progresses, plants receiving less water are using less water and are also significantly more stressed. Additionally, the longer a period of drought they experience, the more dramatic these levels of stress are. This means that if these plants receive deficit irrigation and are subjected to a period of extreme drought, it is possible they may not be able to survive, while their well-watered counterparts will survive. Considering this was a two year study, these results would likely be exacerbated as time progresses. This information suggests that watering Schizachyrium scoparium 'Blaze' at 25% irrigation is possible. However, irrigation events may need to be more frequent to compensate for the additional stress.

Conclusion

When combining the results of both studies, plants grown in the 25% treatment are as aesthetically pleasing and physiologically healthy as those in the 100% treatment. However, if these plants are ever subject to periods of drought they are much more likely to succumb to physiological stress than those in the 100% treatment. This implies that ornamental grasses put on a deficit irrigation schedule must be constantly watered to ensure health and aesthetics. In order to recommend this practice to growers, landscapers, homeowners, and municipalities, a weekly water budget was created. The amount of water to apply on a weekly basis is 0.25 inches (including precipitation). It is important to note that years with significantly more drought will have higher water demands. However, the number of 0.25 inches is relatively sure to allow ornamental grasses to grow to their full potential while maintaining low levels of stress.

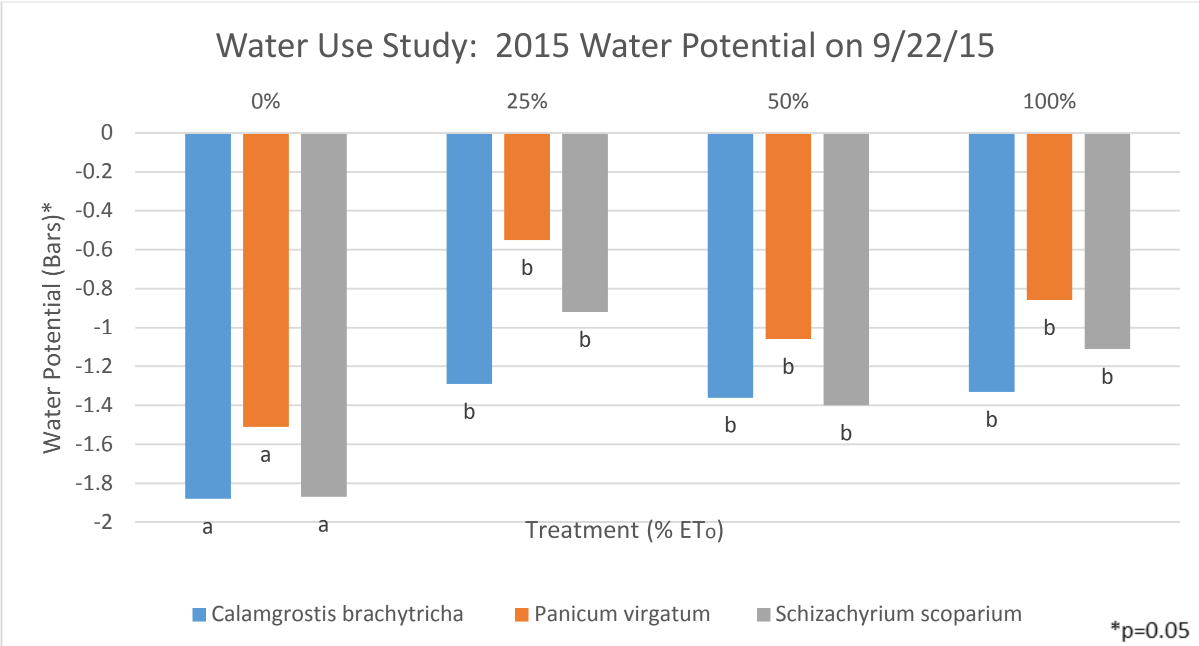


Figure 1: Representative trend of 2015 water potential by treatment in Water Use Study. All species in the 0% treatment were significantly more stressed while the 25%, 50%, and 100% treatments showed no differences.

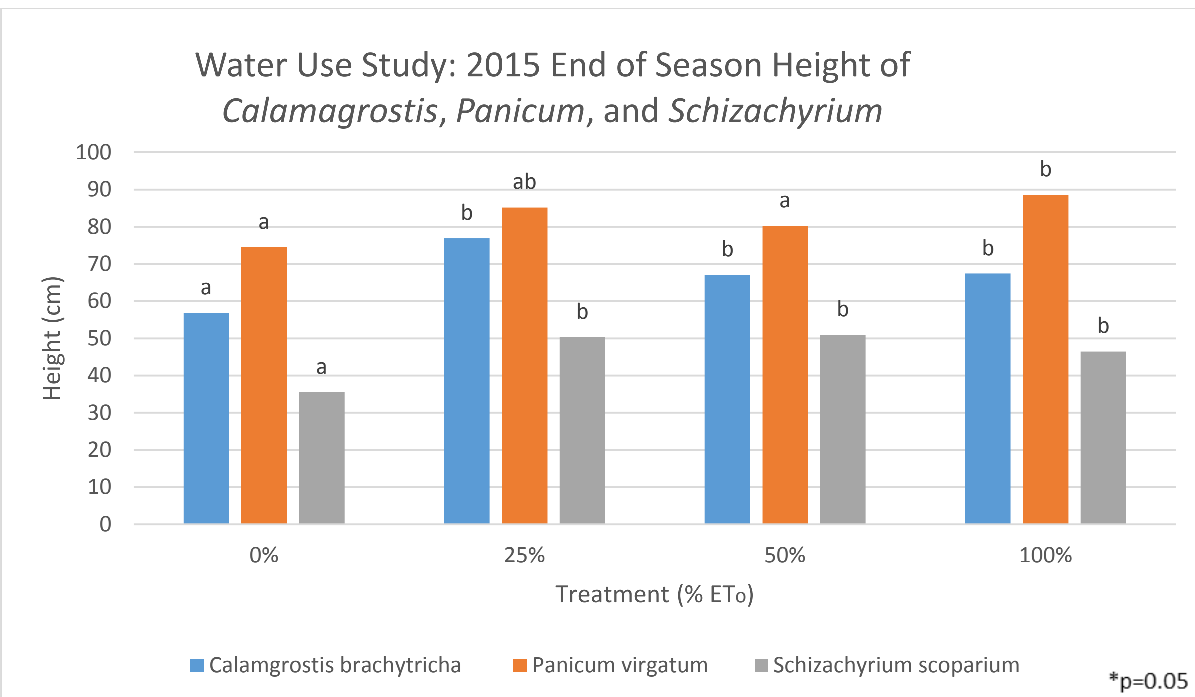


Figure 2: 2015 end of season height of all three species in Water Use Study. The trend still in place was the 0% treatment was shortest, while plants in the 25% treatment were tallest.

Figure 3: Photographs of *Calamagrostis brachytricha* in Water Use Study at the beginning of flowering season. Treatments from left to right: 1) 0%, 2) 25%, 3) 50%, 4) 100%.

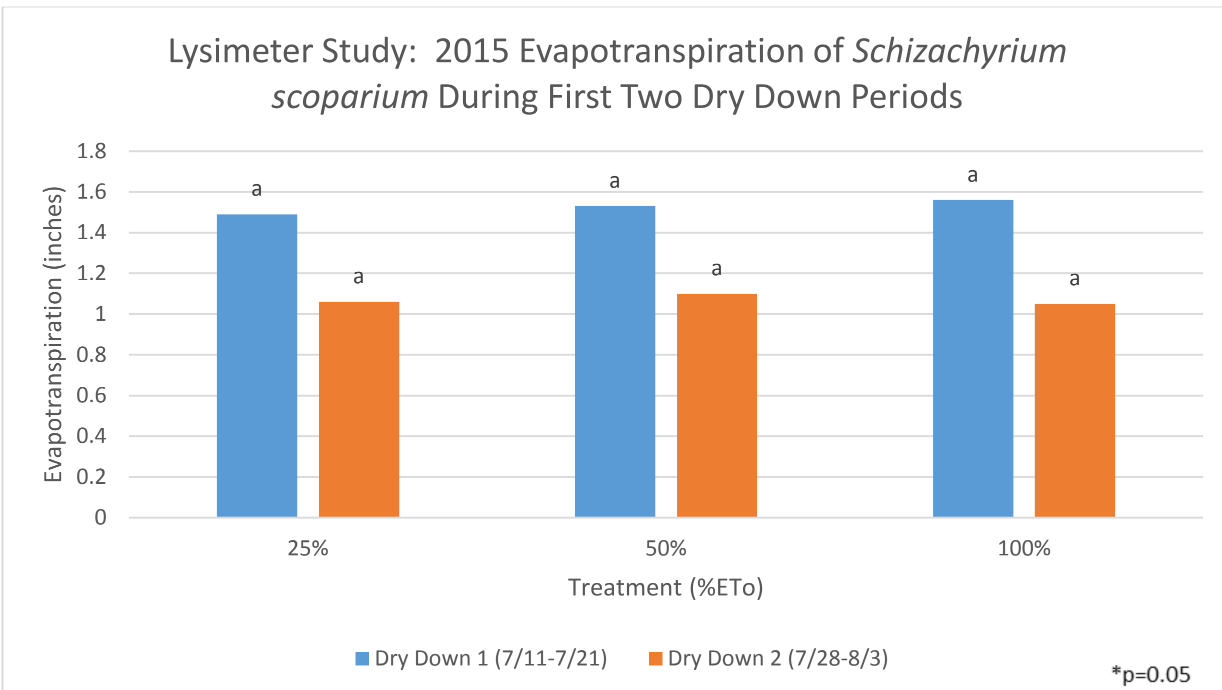


Figure 4: 2015 evapotranspiration during the first two dry down periods in the Lysimeter Study. There was no difference in evapotranspiration between treatments.

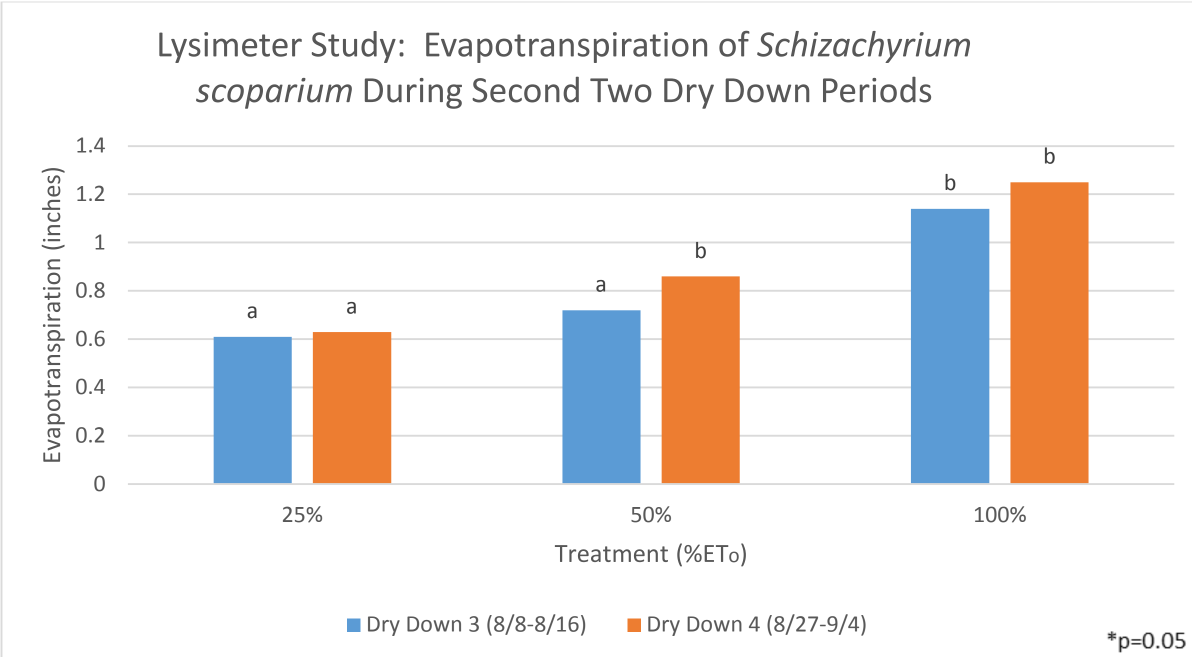


Figure 5: 2015 evapotranspiration during the second two dry down periods in the Lysimeter Study. During the third dry down (blue bars), the 25% and 50% treatments used less water than the 100% treatment. During the fourth dry down, the 25% treatment used significantly less water than the 50% and 100% treatments.

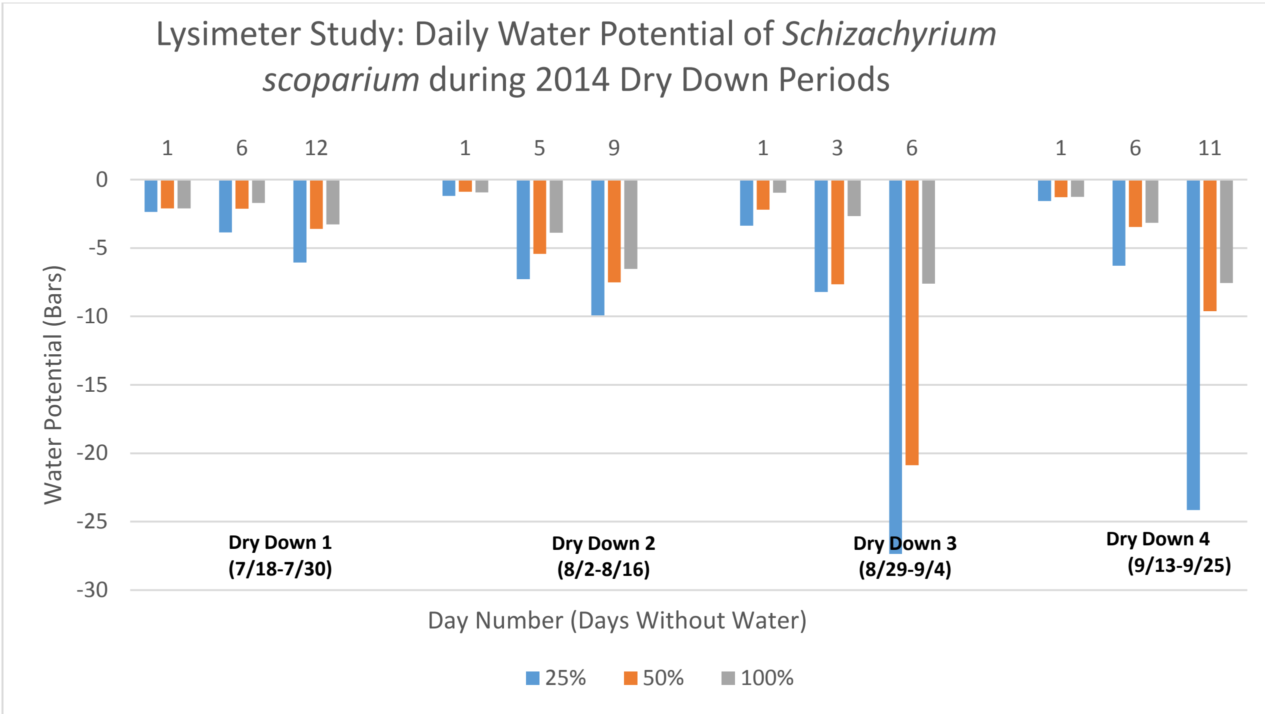
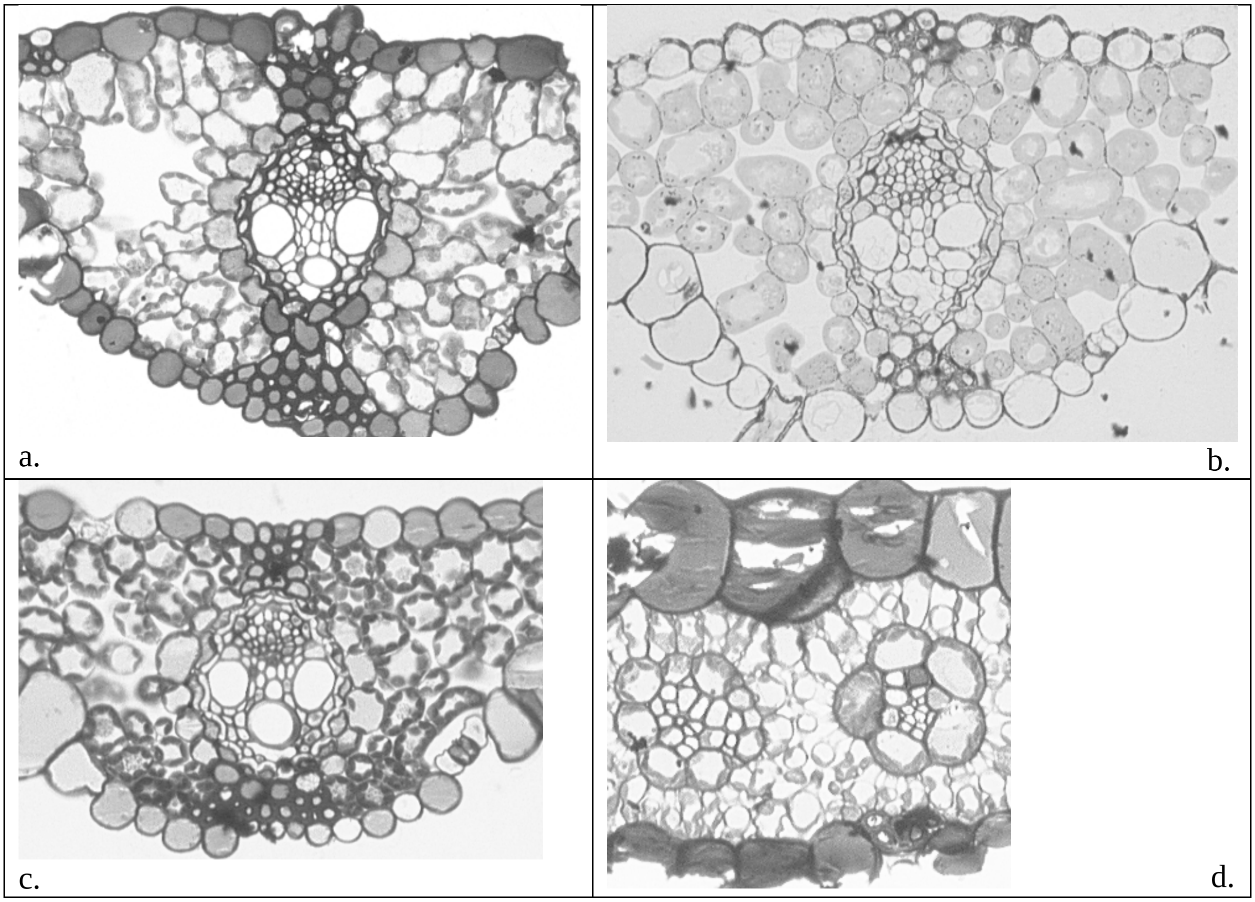


Figure 6: Daily water potential during all four dry down periods of 2014 in the Lysimeter Study. The graph emphasizes the lack of stress during early season drought periods, and a large increase in stress during late season drought periods. The significant level of stress (Bars) is also seen. The 25% treatment is always significantly more stressed once the plants reach 5 to 7 days without water. Note, since each dry down period was dictated by outdoor weather, dry down periods lasted a variable number of days. The graph depicts the start and end date, as well as the best representation of the middle date for that dry down period.



Figures 7: Ornamental grass leaf vasculature cross sections.
a) *Calamagrostis* × *acutiflora* 40x cross section; b) *Calamgrostis brachytricha* Field 40x cross section; c) *Calamgrostis brachytricha* Greenhouse 40x cross section; d) *Schizachyrium scoparium* 40x cross section. All samples of *Calamgrostis brachytricha* show clear vasculature lacking bundle sheath cells, confirmation that *Calamgrostis brachytricha* has a clear C_3 anatomy. Samples were taken at various growth stages to ensure *Calamgrostis brachytricha* was not a transition or obligate C_3 species. Figures 9a-d samples represent vasculature at all growth stages for all species.

Shaping Water Access and Allocation: A Relational Analysis of Water Use for Oil and Gas Development in Colorado

Basic Information

Title:	Shaping Water Access and Allocation: A Relational Analysis of Water Use for Oil and Gas Development in Colorado
Project Number:	2015CO311B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Social Sciences
Focus Category:	Agriculture, Law, Institutions, and Policy, Management and Planning
Descriptors:	None
Principal Investigators:	Melinda Laituri

Publications

There are no publications.

Final Report for Project

Title: Shaping Water Access and Allocation: A Relational Analysis of Water Use for Oil and Gas Development in Colorado

Investigator: Karie Boone, PhD Candidate, Geosciences, Colorado State University

Advisor: Dr. Melinda Laituri, Ecosystem Science and Sustainability, Colorado State University

Introduction

The state's Division of Water Resources considers water use for oil and gas (OG) extraction activities as short-term and an insignificant percentage of Colorado's overall water consumption. The Statewide Water Supply Plan makes no mention of concern about OG water uses; and OG activities are not represented at the Basin Roundtables, a state initiated water governance mechanism mandated to integrate bottom-up, local decision-making into the State's Water Plan. These are the predominant entities responsible for guiding water policy and while Colorado's institutions were built on the premise of mining interests, the contemporary pace and scale of energy extraction represents a new phenomenon that has not been critically examined. Indeed, the quantity and sourcing of water for OG operations is not accurately documented or fully understood by state agencies. At the same time, the number of active OG wells in the state has gone from 22,500 in 2002 to almost 54,000 in 2016. Changing water use is particularly important on the South Platte River in Weld County and the Colorado River in Garfield County since they contain the largest percentage of active wells with 22,724 and 11,067 OG wells respectively. Throughout its lifecycle, each well uses between 3-8 million gallons, or between 9-24 acre feet of water. To meet the increasing demand for OG use, water suppliers, right holders, and Colorado's diverse community of users are innovating ways to navigate the rules governing water access and allocation to find flexibility in the state's water institutions.

With financial support from the National Institutes for Water Resources and the Colorado Water Institute, this research study examined how OG water users are able to find flexibility in the system when other uses have not, who is impacted by this type of flexibility, how, and what it means for access by other users. What does differential access look like if it exists and what does its presence illuminate about the system of prior appropriation? A comparative case study was conducted, spanning the U.S. Continental Divide to investigate divergent influence and change of OG water use in Garfield and Weld counties to examine these questions (Figure 1). These regions are of particular importance since they are located above Colorado's most productive OG fields, the Piceance and Denver-Julesburg Basins respectively. These regions have differing shale geologies, land tenure (private versus publically owned), divergent regional histories and water sourcing strategies related to OG extraction. Identifying how increased water use for OG shapes and is shaped by the institutions of water rights both historically and in new ways will inform adaptive policy-making and institutions.

Methods

A comparative case study methodology provided the necessary in-depth examination of the 'how' and the 'why' of social and political change processes, an important step in building our understanding of water access and allocation mechanisms. State water institutions, policy, and local level decision-making comprise the ideal space to examine the actions and daily experiences of institutional decision-making on individual actors while compiling data that offers insights into larger scale changes in Colorado's water governance. A mixed-methods approach was used to integrate historical institutional analysis, document analysis of water rights, in-depth interviews, and geographic information systems (GIS). The historical institutionalist method traced the development of water rights and national energy policy as it related to OG development.

Then, an analysis of water rights for OG development was based on identifying current water sourcing strategies in Weld and Garfield counties. Data were gathered from published research and a document analysis of primary source formal water court agreements including Substitute Water Supply Plans (SWSPs) and Water Right Decrees.[1] The analysis of legal documents collected from government databases were evaluated in three phases. First, a literature review identified strategic search terms to locate the relevant water right decrees and short-term lease agreements (SWSPs) from the Colorado Division of Water Resources (DWR) online databases Laserfiche (http://dwrweblink.state.co.us/) and HydroBase (http://water.state.co.us/DataMaps/Pages/default.aspx). Search terms fit into categories of energy company, water provider, transport names, county, water uses, and key terms including oil and gas.

The second phase applied a Boolean search logic to locate the relevant water rights and SWSPs in the government databases from 2000-2014, a time frame including the height of OG production and the subsequent decrease of drilling activities and water use. Boolean searches consisted of combinations of county name, energy company, water organization name, and keywords such as 'natural gas' and 'oil'. Records returned from searches were organized using a common naming convention for systematic document and folder organization. Phase three entailed the document analysis using coding for applicant and water right holder name, diversion location,

[1] SWSPs are short-term augmentation plans utilized when an individual or company has a water right application being reviewed by the water court. Water rights, or decrees, are a legal document adjudicated by the state water court that defines a user's usufructory right to put a particular amount of water from a specific location to beneficial use.

appropriation date, water source, decreed use(s) and volume, and proposed new use(s).

Then, interviews with farmers and ranchers, water managers, and OG company representatives shed light on how access and allocation is or is not flexible for multiple uses and/or sites of differential water access. In this case, utilizing qualitative interview methods provided the means to gain a better understanding of local definitions, perceptions and behaviors on the core topics of water access and allocation related to OG development, or how this institutional change is experienced by people on the ground.

Trends in Oil and Gas Water Access and Allocation in Weld and Garfield Counties

Water rights have evolved differently across Weld and Garfield counties and within the South Platte and Colorado River Basins (See Figure 1). Thus, OG operators in these two counties acquire water through distinct access mechanisms. The South Platte River Basin flows through Weld County, out towards eastern Colorado, and Nebraska. The river supplies the greatest concentration of irrigated agricultural lands in Colorado with 85% of water used to irrigate 831,000 total acres representing 24% of the state's irrigated acres. OG began in the early 2000s and Weld County is the top producing county with 22,108 active oil and gas wells. Operators purchase water rights from agriculture and have short-term leasing arrangements including SWSPs from a variety of private entities. These entities include water haulers, municipalities and increasingly from stakeholder-driven irrigation and reservoir companies, particularly those leasing water diverted from the Colorado River Basin through the Colorado Big Thompson (CBT) project. CBT water is diverted from western Colorado, under the Continental Divide and into the South Platte River Basin flowing across the Eastern Plains in Colorado. CBT water is legally multi-use (i.e., municipal, industrial, irrigation) and considered more flexible since water can be leased to diverse use types without long and costly water court change of use cases. The South Platte River is over-appropriated, meaning that there are more legally sanctioned water uses then there is water, OG operators are nevertheless able to access water for OG development.

On the western side of the Continental Divide, Garfield County is the second largest producing county after Weld County with 11,000 active wells and located on the main stem of the Colorado River Basin (CRB). The main stem of the CRB has 268,000 or 8% of the state's irrigated acres of farm and ranch lands. OG operators lease small amounts of CRB water from private entities such as ranchers and conservancy districts, however, the predominant trend is for OG companies to own their own water rights. These rights were acquired from agriculturalists starting in the 1940s in anticipation of a federally funded oil shale boom. Many of these rights remain as 'conditional', meaning they have reserved a place in the priority list, have proven intent to divert the water by taking a justifiable first step toward development, but do not immediately need to put the water toward a beneficial use. A conditional right holder intends to make beneficial use of the water for some sort of future development, in this case oil and gas extraction. [2] The different access and allocation mechanisms across the two counties represent divergent interpretations of the same institution of prior appropriation rooted in unique contexts and histories.

Conclusion: Reflection on Research Experience

This research project has provided the opportunity to get to know a diversity of water users, understand their interests, concerns, and vision for the future of water access and allocation in Colorado. The Colorado's water community has been generous for their time to interview and respond to questions about water rights and OG activities. Participating communities share a lot in common while at the same time work through points of contention and historical grudges. Despite the diversity and challenges there remains a common mission to do what is necessary to keep water for agriculture alive in Colorado.

Colorado's water institutions and rights change and adapt relationally with changing uses on the South Platte and Colorado Rivers, generating contemporary water accessibility for the state's diverse users. To understand these processes social complexity is defined and integrated through a relational examination of historic policy outcomes, their influence on contemporary water allocation and access, changing water use for OG, and the physical nature of water as continually evolving and shaping one another. This integration links the hydrological and social while further enriching our understanding of how adaptive water governance is iteratively shaped through this same relational process.

In sum, issues of water access related to OG development have been identified piecemeal through individual conversation and in newspaper articles demonstrating the real concerns of farmers, environmental groups, and state legislators. No substantive studies have examined the tradeoffs of water access for the state's diverse users. While water quantity for extraction is still contested, a sufficient amount of data has been gathered from this research study, specifically from the Division of Water Resources' database to identify changes in water rights precipitated by increased OG production. If differential access is occurring, water policy should account for it and insure all users have access to beneficial uses, particularly as the state moves toward more flexible water administration mechanisms. At the same time, formal policy often has divergent impacts on groups of people. This research examines these potential impacts and tradeoffs and will propose policy alternatives. The data analysis is still continuing, so stay tuned for comprehensive research findings this Fall!

---

[2] Every six years conditional water right holders must demonstrate that they are making progress toward a beneficial use of the water and that the appropriation can and will be completed. This process is termed "due diligence".

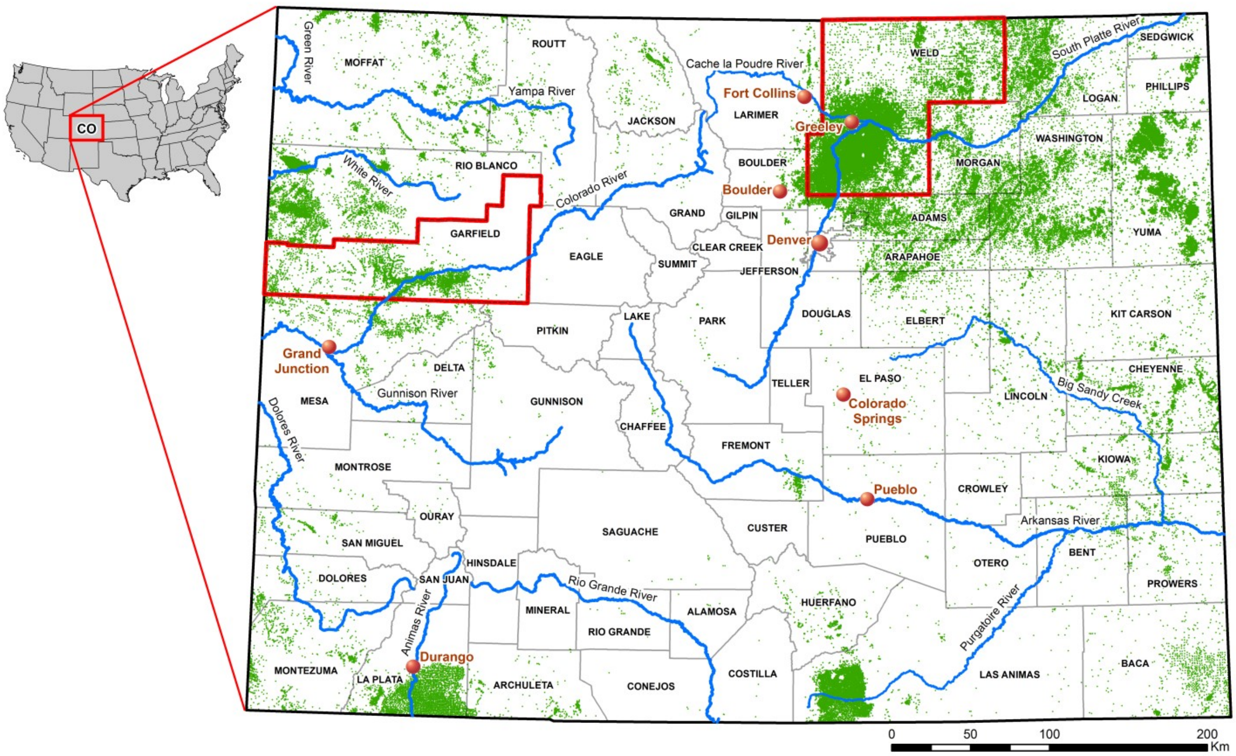


Figure 1: Map of Colorado with oil and gas development highlighted in green and the counties of study outlined in red (Oikonomou et al. 2015; under review)

Spatiotemporal Assessment of Groundwater Resources in the South Platte Basin, Colorado

Basic Information

Title:	Spatiotemporal Assessment of Groundwater Resources in the South Platte Basin, Colorado
Project Number:	2015CO312B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	CO-007
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Hydrology, Models
Descriptors:	None
Principal Investigators:	John E. McCray

Publications

There are no publications.

Final Report for Project

Title: Spatiotemporal Assessment of Groundwater Resources in the South Platte Basin, Colorado

Investigator: Christopher J. Ruybal, PhD Candidate, Civil and Environmental Engineering, Colorado School of Mines

Advisors: Dr. John E. McCray and Dr. Terri S. Hogue, of Civil and Environmental Engineering, Colorado School of Mines

Introduction

In recent years, the water-energy nexus emerged in the crosshairs of public debate. Until the downturn in June 2014, oil and gas production reached historic levels due to hydraulic fracturing and directional drilling, helping drive production in low-permeability, unconventional reservoirs. This historic production continues to generate controversy and discussion regarding environmental, public health, and social concerns.

While much attention has centered on issues of groundwater contamination from hydraulic fracturing operations, less has focused on the added competition for water resources. The growing need for water among urban users, agriculture, industry, ecosystems, and now increased energy development, presents challenges in over-appropriated and water-limited systems.

Colorado is recognized as one of the top ten oil and gas producing states. Within the Niobrara Shale and Codell Sandstone, the Wattenberg Field has emerged as the sweet spot for crude oil and natural gas liquids (Figure 1).

A recent Ceres report found that 97% of oil and gas wells drilled in Colorado are in areas classified as experiencing high or extremely high water stress. A recent study by Ella Walker and colleagues at the Colorado School of Mines, in the Center for a Sustainable WE^{2}ST, identified that while state-wide water demands for hydraulic fracturing in Colorado are relatively low, accounting for 0.24% of the state's consumptive water use, local use is much more significant, accounting for nearly 7% of the consumptive use for the city of Greeley in 2014. Water use for the same period within the South Platte Basin averaged around 11,100 m^3 (~9 AF) for horizontal wells and 1,100 m^3 (~0.9 AF) for vertical wells.

Water sourcing options for oil and gas production are similar to any other water user. Surface and tributary groundwater sources are the most challenging sourcing options due to over-appropriation and users needing to obtain a water right, develop augmentation plans for water taken out of priority, and legally change the beneficial use of the water right. Because energy development demands are short-term, more enticing options include leasing water from agriculture, municipalities, water well users of non-tributary groundwater, or drilling new wells to utilize non-tributary groundwater.

Municipalities such as Erie, Fort Lupton, Aurora, Greeley, and Longmont, Colorado already lease excess water to oil and gas companies.

Objectives

Lack of rigorous water accounting has limited the ability to fully understand any additional stresses that oil and gas operations may place on aquifers. The overarching goal of this research is to evaluate the potential impacts of oil and gas production on groundwater resources within the South Platte Basin to better manage current and future water resources within the region. Specifically, objectives included (i) identifying areas that are experiencing significant energy development and competition for groundwater and (ii) utilize ground-based and satellite data to improve understanding of regional aquifer stresses and variability.

Methods

Ground-based data

Initial analysis of regional aquifer stress was performed using water level measurements from traditional groundwater observation wells. Within the South Platte Basin, the principal aquifer systems include the South Platte Alluvial Aquifer and the Denver Basin Aquifer System. These systems consist of four vertically sequenced aquifers in different geologic formations that encompasses approximately 6,700 square miles, as seen in Figures 1 and 2. Approximately 9,726 observation wells were identified using data from the Colorado Division of Water Resources. However, 94% of the wells identified, had only one groundwater level measurement in time, likely when the well was installed. 8,408 wells logs did not identify the aquifer for the screened interval. A smaller subset of observation wells with data from the past 20-years was selected. This included 64 wells within the Laramie-Fox Hills Aquifer, 165 within the Arapahoe Aquifer, 80 within the Denver Aquifer, 54 within the Dawson Aquifer, and 178 within the South Platte Alluvial Aquifer.

Satellite-based data

In 2002, NASA launched the Gravity Recovery and Climate Experiment Satellites (GRACE) with German partners to measure monthly spatial and temporal changes in the Earth's gravity field. By measuring changes in gravity, water storage changes in surface waters, snow, ice, soil moisture, and groundwater can be inferred. Auxiliary datasets from remote sensing satellites and land surface or global hydrologic models can be used to determine individual components of soil moisture, snow water equivalent, and surface waters. These components are then subtracted from the GRACE terrestrial water storage signal, where the residual is attributed to groundwater storage changes. GRACE data from three processing centers (University of Texas at Austin Center for Space Research, GeoForschungsZentrum Potsdam, NASA Jet Propulsion Laboratory) were processed to scale the data and create an ensemble of averages of the three data centers. Values were then converted from equivalent water height in centimeters to cubic kilometers using the area of GRACE grid pixels.

Preliminary Results and Discussion

Most groundwater wells are irregularly sampled, once per year, leading to large gaps in the data that limit the understanding of spatial and temporal changes occurring. For example, the Laramie-Fox Hills Aquifer for a given year may have only one well observation measurement per 100 square miles. Long-term trends in groundwater levels throughout the various aquifers of the Denver Basin Aquifer system are highly variable (Figure 3). A Mann-Kendall Test of trend was applied to each aquifer series (moving average of median water level) to evaluate whether a significant increase or decrease trend existed from 1995 – 2015. Results of the trend test indicates that both the Laramie-Fox Hills and Dawson Aquifers have significant decreasing trends ($p<0.05$) for the 20-year time series. Similarly, both the Arapahoe and Denver Aquifers have significant increasing trends ($p<0.05$) with time.

Long-term changes in groundwater may reflect changes in recharge rates due to anthropogenic effects or variations in climate. Although seasonality was removed using a moving average (Figure 3), seasonal fluctuations in water level elevations are also common due to variation in precipitation, evapotranspiration, groundwater pumping, and irrigation. Water level differences between the aquifers may indicate vertical water movement throughout confining units and may be influenced by the relative amounts of groundwater pumping each aquifer receives. The upper portion of the Laramie-Fox Hills aquifer though is relatively impermeable, and may prevent downward vertical movement of water from the above aquifers. The decreasing trend in this system may be a result of groundwater usage exceeding mountain block recharge rates to the aquifer.

For water resources planning, reliable temporal data are needed to enable predictions of groundwater storage changes (either from models or trend analysis). Given the relative temporal sparseness of current well data, it is hypothesized that monthly GRACE data can improve the current uncertainty associated with groundwater quantity analysis along the Colorado Front Range. Monthly GRACE derived groundwater storage anomalies (km^3) for a grid pixel centered over the Denver Basin Aquifer System were compared to 277 ground-based observation wells (Figure 4). Each observational well was normalized for comparison to GRACE since at the time, the aquifer properties (i.e. specific storage, specific yield, aquifer thickness) were unknown and needed to convert a head measurement into a volumetric change.

Comparison of the water levels for the cumulative well observations for all aquifers are consistent with the increasing and decreasing patterns detected by the GRACE satellites. The response of each aquifer contributes to the observed GRACE signal. Long-term depletion rates over the Denver Basin Aquifer System from the GRACE signal amount to 0.008 km^3/year (~6,500 AF/year). Previous U.S. Geological Survey (USGS) reports identify depletion rates in the Denver Basin bedrock aquifers from 2002 – 2008 as 0.007 km^3/year. For comparison, the GRACE determined depletion rate from 2002 – 2008 was 0.007 km^3/year, matching the reported values from the USGS.

Comparison of GRACE with the U.S. Drought Monitor, which reports on the extent and magnitude of drought, shows a correlation between groundwater response during wet and dry periods associated with the variable climate. In early 2011, approximately 80% of the South Platte Basin was characterized as being in moderate drought, and by 2012 to mid-2013, the entire basin ranged from moderate to exceptional drought. The drought severity is consistent with GRACE derived groundwater depletions and trends during this drought period.

Early results indicate that the satellite based data may be useful for managing and understanding groundwater resources over the South Platte Basin, and can help reduce uncertainty due to missing spatial and temporal groundwater level data. Significant long-term trends exist for each of the four aquifers of the Denver Basin Aquifer System which are likely due to a combination of natural and anthropogenic effects.

This work indicates the importance of good temporal and spatial data that are needed to investigate groundwater storage changes. To evaluate the potential impacts of oil and gas production on groundwater resources within the South Platte Basin and to better manage current and future water resources in the region, ongoing work includes the following (i) obtaining aquifer properties for each observation well to enable estimates of water storage changes from ground-based data, (ii) evaluating the limits of GRACE when applied to smaller scale basins and providing a comparison to observational well data, (iii) evaluating depletion rates before and after the increase in energy development, and (iv) developing a high resolution groundwater model of the region, using spatiotemporal data to assess recharge regimes under current and future climate and land use.

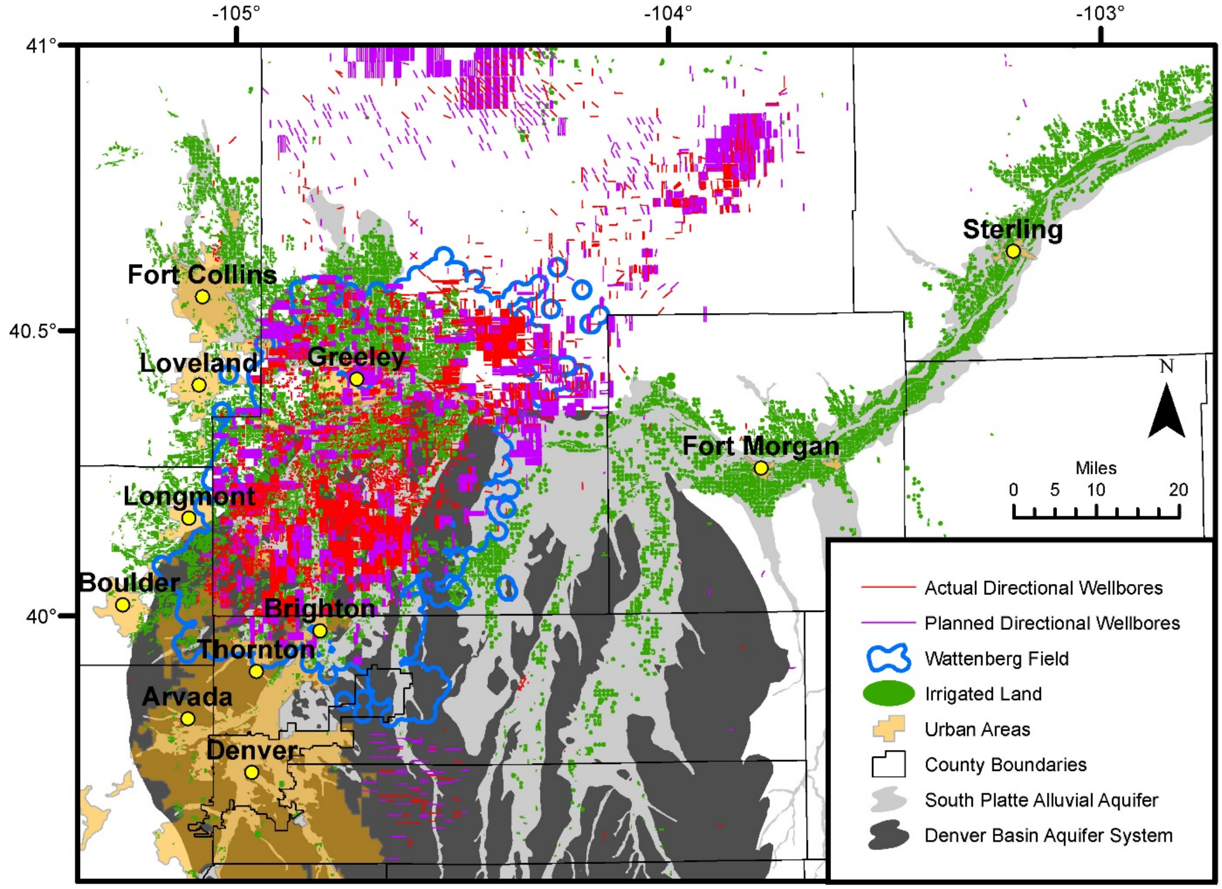


Figure 1. Map showing actual and future drilling operations in relation to principal aquifer systems, urban areas, and irrigated land within the South Platte Basin.

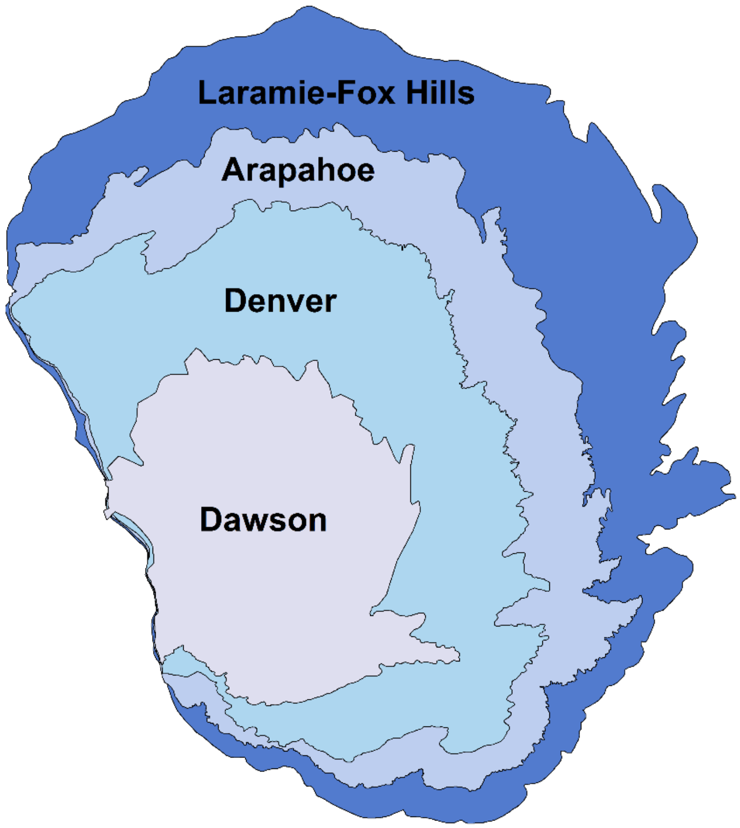


Figure 2. Map of aquifers within the Denver Basin Aquifer System illustrating size and position. The shallowest aquifer is the Dawson and the deepest is the Laramie-Fox Hills Aquifer.

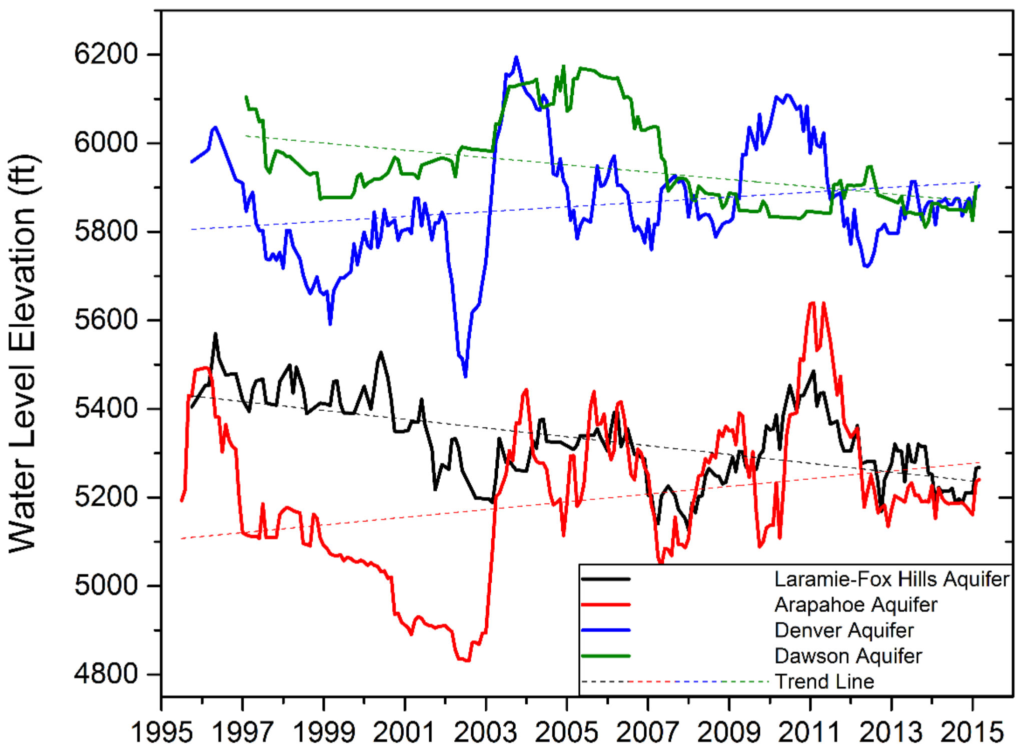


Figure 3. Moving average of median water level elevations for aquifers of the Denver Basin Aquifer System from 1995 – 2015.

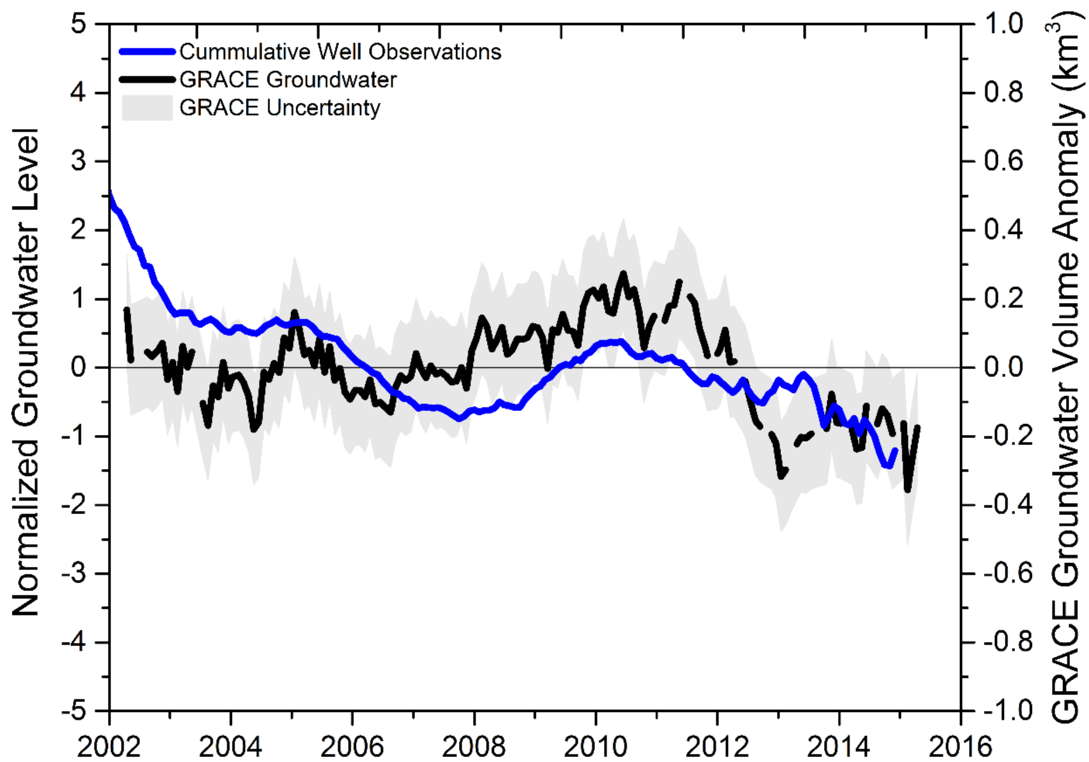


Figure 4. Comparison between well observations and GRACE derived groundwater storage anomalies (with seasonality removed) for Denver Basin Aquifer System.

Floating Wetlands Systems: Managing Aquatic Plants as a Salt and Se Sequestration Strategy

Basic Information

Title:	Floating Wetlands Systems: Managing Aquatic Plants as a Salt and Se Sequestration Strategy
Project Number:	2015CO313B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	CO-003
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Solute Transport, Surface Water
Descriptors:	None
Principal Investigators:	Gigi Richard

Publications

There are no publications.

Final Report for Project

Title: Floating Wetlands Systems: Managing Aquatic Plants as a Selenium Sequestration Strategy

Investigator(s): Craig D. Moore, BS Student, Environmental Science and Technology, Colorado Mesa University

Advisor(s): Dr. Gigi Richard, Physical and Environmental Sciences, Faculty Director for the Water Center at Colorado Mesa University; Dr. Perry E. Cabot, Research Scientist and Extension Specialist, Colorado Water Institute

---

Introduction

Excessive concentrations of selenium (Se) in natural water systems is of growing concern in western Colorado. A non-metal chemical element, Se is an essential human micronutrient in small doses. However, at elevated levels Se is a bioaccumulative toxin to aquatic wildlife. Spinal deformities, death in fish, and embryonic deformities in waterfowl have been attributed to excessive concentrations of Se in waterbodies. The Se content of several rivers in Colorado originates from a variety of geochemical sources of dissolved solids in surface water and alluvial groundwater. Primary among these sources are the Mancos Shale in western Colorado, extending across the Colorado Plateau, and the Pierre Shale east of the Rocky Mountains. Deep percolation from diverted irrigation water leaches Se from the lower soil profile, providing pathway for discharge to river systems.

Soil and surface water concentrations of Se in the Uncompahgre, Lower Gunnison and Upper Colorado River regions are some of the highest in the country. Percolation of irrigation water through the local Se laden soils has been described within the Department of the Interior's Programmatic Biological Opinion (PBO) for the Aspinall unit as inhibiting recovery of four local endangered fish species and concentrations in the Gunnison River at Whitewater exceed the state chronic standard (4.6 ppb). Approximately 8000 pounds per year of Se needs to be eliminated from the current Se load to the Upper Colorado Basin in order to meet the water quality standard acceptable for local endangered fish species. Numerous sloughs, ponds, and abandoned gravel pits sit adjacent to the Colorado River in Mesa County and these areas are important wildlife habitat and breeding grounds. These areas can also be hotspots for toxic Se concentrations. Aqueous Se has been found in these systems in excess of 100 ppb and tends to accumulate in bottom sediments.

Several stream segments within the Arkansas River Basin, including Wildhorse Creek and certain segments along the Arkansas River are also currently listed on the Colorado Department of Public Health and Environment (CDPHE) 303(d) list for Se, indicating that this issues is a statewide problem. Concentrations of Se in these reaches regularly can exceed the chronic toxicity level for aquatic life.

Prior studies have successfully demonstrated the Se phytoremediation capability of several halophytic wetland plant species in a laboratory setting. The purpose of this project is to demonstrate that a consortium of halophytic plant species in a managed floating wetland system is capable of improving water quality by taking up and sequestering Se in their root tissue and leaf and stem (referred to collectively as "shoot") tissue under field conditions. Floating wetland systems of the type described in this paper have been used in Midwestern United States studies to uptake nitrogen (N) and phosphorous (P) from storm water detention ponds. This project had the goal of expanding the examination of floating wetlands for Se remediation.

Methods

Four species of wetland plants were selected for their demonstrated or predicted ability to take up and accumulate Se from an aquatic system, for salinity tolerance, and for regional availability. Test species were taken or derived from the 1999 study of Pilon-Smits et al. (1999). Twenty replicates of each of the following species were purchased from AlpineEco Nursery in Denver, Colorado: Nebraska Sedge (*Carex nebrascensis*), Common Spikerush (*Eleocharis palistrus*), Baltic Rush (*Juncus* balticus), and Panicled Bulrush (*Scirpus microcarpus).*

Floating wetland mats were purchased from Beemats™, in New Smyrna Breach, Florida, and assembled at the study site. Beemats are comprised of buoyant, interconnecting square foam mat sections. Each mat section has an area of 60 cm x 60 cm, is 1 cm thick, and holds ten cups which each house plant replicates.

Study Area

The study site was a gravel pit pond known to exhibit excessive concentrations of Se. The pond is located adjacent the Colorado River in Mesa County, Colorado, and access was granted by the Mesa County Public Works Department. The constructed floating wetland was installed at the study site in July, 2015 and extracted in October, 2015. Following removal, measurements were taken for root depth and stand height. Plants were dried for at least 48 hours at approximately 80°C and separated into their constituent root and shoot (leaf and stem) systems, after which the mass of the separated aliquots were recorded. The samples were then grounded using a laboratory blender and subsequently underwent chemical analysis for Se at ACZ Labs in Steamboat Springs, Colorado using the Environmental Protection Agency's method M6020 ICP-MS. Two additional replicates of each species were designated as reference samples. These individuals were grown in greenhouse conditions and also analyzed for Se concentration. The species specific reference concentration was subtracted from each treatment concentration to obtain the Se concentration accumulated from the study site by each treatment replicate. The average selenium concentration of each replicate was determined by subtracting the reference concentration from the final concentration after the field season

Results

Following a four-month residence at the study site, average total biomass of the test species was as follows: Panicled Bulrush, 6.5 g per replicate; Common Spikerush, 4.5 g per replicate; Baltic Rush, 3.5 g per replicate; Nebraska Sedge, 1.8 g per replicate. Baltic Rush and Common Spikerush held the majority of their biomass in their roots, while the Panicled Bulrush and Nebraska Sedge had greater mass in their shoots (Figure 1). Common Spikerush, Baltic Rush, Panicled Bulrush, and Nebraska Sedge grew to average heights of approximately 42 cm, 41 cm, 39 cm, and 5.8 cm, respectively (Figure 2). Roots grew to depths of 53 cm, 45 cm, 44 cm, and 22 cm, for Panicled Bulrush, Common Spikerush, Baltic Rush, and Nebraska Sedge, respectively. Nebraska Sedge experienced a 70% mortality rate, while the Panicled Bulrush, Baltic Rush, and Common Spikerush experienced a 100% survival rate. One Common Spikerush was lost at the study site.

The greatest average Se concentration was found in the root tissue of the Panicled Bulrush*, 3.8 mg/Kg.* Average Se concentration present in the root tissue of Common Spikerush*,* Baltic Rush*,* and Nebraska Sedge were 3.5 mg/Kg, 3.3 mg/Kg, and 2.7 mg/Kg, respectively (Figure 3). All species showed higher Se concentrations present in root tissue than in shoot tissue. Panicled Bulrush contained greater Se concentrations in roots than shoots by a factor of of approximately three, Baltic Rush by a factor of approximately four, Nebraska Sedge by a factor of approximately five, and Common Spikerush by a factor of approximately seven. The Panicled Bulrush also had the highest Se concentration among all plant species in terms of shoot material, 1.2 mg/Kg. Common Spikerush, Baltic Rush, and Nebraska Sedge had average shoot concentrations of 0.5 mg/Kg, 0.7 mg/Kg, and 0.5 mg/Kg, respectively.

Discussion

The study documented that Panicled Bulrush outperformed the other three species in terms of plant growth, Se sequestration, and total biomass. On the basis of this study, Panicled Bulrush is is the best candidate for Se phytoremediation under a larger deployment. Positive results among Common Spikerush and Baltic Rush suggest that these species may also be candidates for further testing. Total Se removal capability is determined by a plant species ability to accumulate Se in its tissues as well as its ability to volatilize Se. Volatilization capability of Common Spikerush and Baltic Rush has been demonstrated by Pilon-Smits et al. (1999). The findings justify future inquiry into the volatilization potential of the panicled bulrush. Additional research that could progress from this study would be to evaluate the total Se load capable of being removed per area unit of floating wetland mats, and the overall impact that a large coverage could possibly have on Se-rich gravel pit ponds.

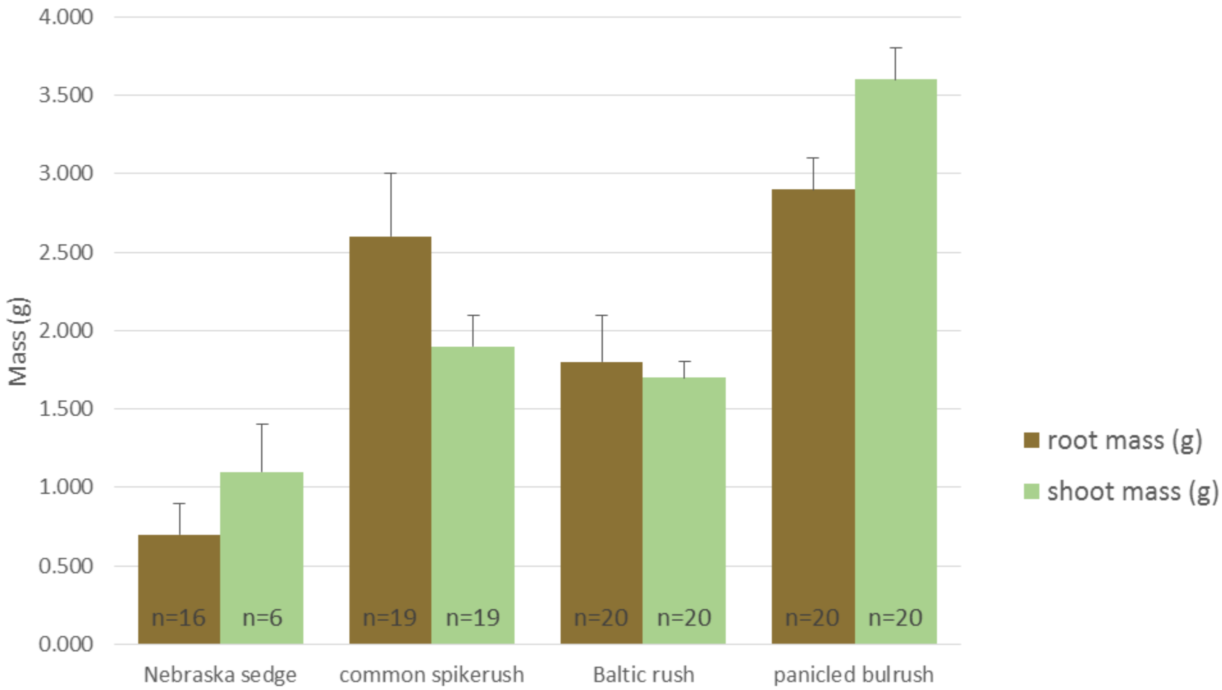


Figure 1. Average plant mass of four wetland plant species after a 4 month residence in a selenium rich gravel pit pond adjacent to the Colorado River in Mesa County, Colorado.

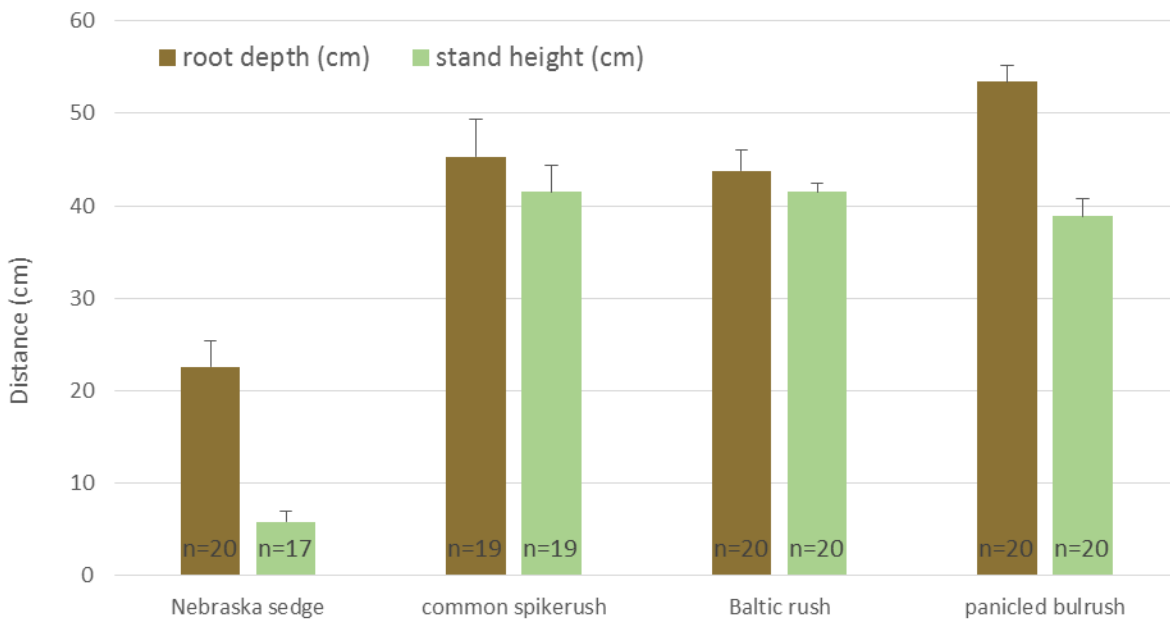


Figure 2. Average root depth and stand height of four wetland plant species after a 4 month residence in a selenium rich gravel pit pond adjacent to the Colorado River in Mesa County, Colorado.

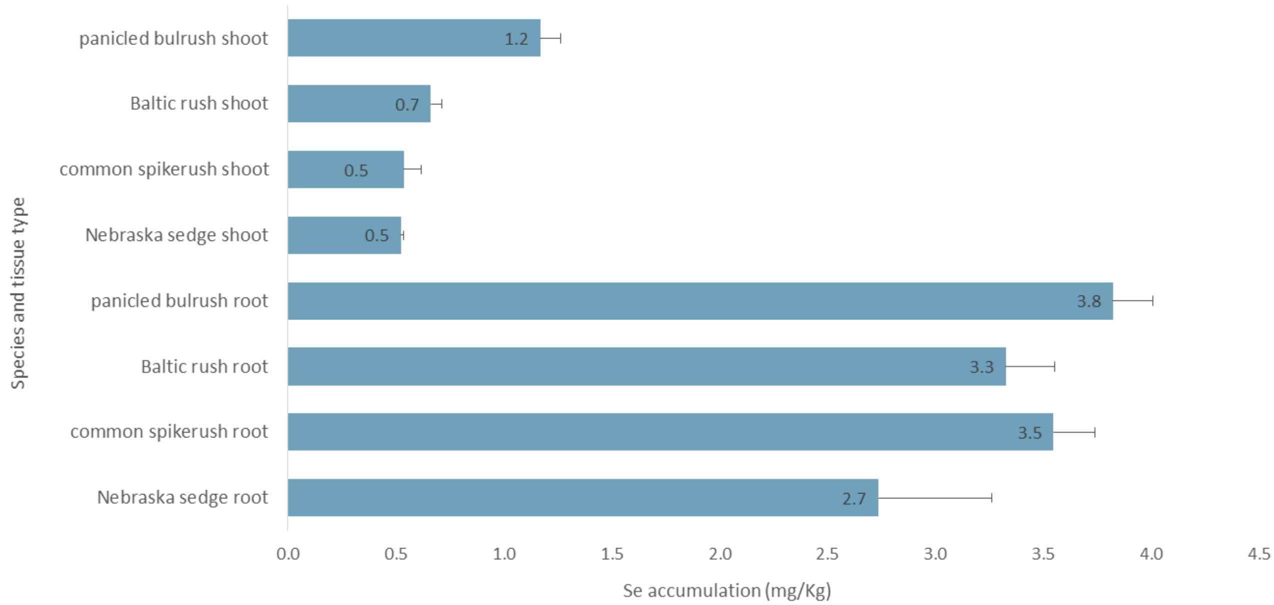


Figure 3. Average selenium concentration (mg/Kg) accumulated by the roots and shoots of four wetland plant species after a 4-month residence in a selenium rich gravel pit pond adjacent to the Colorado River in Mesa County, Colorado.

Nutrient Retention and Productivity in Rocky Mountain Streams Under Alternative Stable States 2014-2015

Basic Information

Title:	Nutrient Retention and Productivity in Rocky Mountain Streams Under Alternative Stable States 2014-2015
Project Number:	2015CO314B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Biological Sciences
Focus Category:	Ecology, None, None
Descriptors:	None
Principal Investigators:	Dana Winkelman

Publications

There are no publications.

Final Report for Project

Title: Nutrient Retention and Productivity in Rocky Mountain Streams Under Alternative Stable States 2014-2015

Investigator: Adam Herdrich, MS Student, Colorado Cooperative Fish and Wildlife Research Unit, Graduate Degree Program in Ecology, Colorado State University

Advisor(s): Dr. Dana L. Winkelman, Unit Leader, U.S. Geological Survey, Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University; Dr. David Walters, U.S. Geological Survey, Fort Collins Science Center

Introduction

Much of the Intermountain West was deforested following European-American colonization in the 19th century. Logging, especially in riparian areas, has significantly reduced the input of large wood to mountain streams throughout this area. Tie-driving (floating logs downstream to use for railroad ties), snag removal, and beaver trapping have further reduced physical habitat complexity, such as channel spanning logjams, in streams.

Logjams reduce water velocities and increase groundwater levels, which facilitate the formation of multi-thread channel reaches and dynamic water exchange between surface and groundwater. High densities of logjams create a positive feedback mechanism that increases wood retention and logjam formation. However, many mountain streams in the Intermountain West have shifted to an alternative stable state, where logjam density is low and both wood retention and logjam formation is greatly reduced. This alternative stable state has a simplified physical habitat template, characterized by a single stream channel and reduced pool habitat.

This research study focused on utilizing the small amount of true old growth forest (> 350 years old) still remaining in the Colorado Front Range (United States) to intensively study patterns in trout density, growth, and diet among two streams with varying riparian forest stand ages (~120 and >350 years old) and logjams densities. As part of our initial effort, data on fish density and growth rates was collected; then diet samples at both sites during summer and fall seasons were also collected to investigate any differences in diet composition between the two sites. Here, presented below are the results on differences in population densities, individual growth rates, and diet composition.

Study Area

Two field sites for intensive sampling were selected including: a high and low wood site (Table 1). Both of these sites were sampled in Summer and Fall 2014 (Table 1). The first site, North St. Vrain, has an order of magnitude more wood per square meter than the second site, Glacier Creek (Table 1). Although the stream area is about the same, the high wood site has about twice the pool area compared to the low wood site (Table 1). It is also important to note that the high wood site is at higher elevation compared to the low wood site.

Table 1. Elevation, riparian forest stand age and stream habitat areas at N. St. Vrain and Glacier creeks.

Site	Elevation (m)	Forest stand age (yrs)	Valley length (m)	Stream area (m^2)	Pool (m^2)	Riffle (m^2)	Wood (m^3)
N. St. Vrain	3017	>350	500	6900	1150	5750	3486
Glacier Creek	2712	122	900	7164	676	6488	312

Methods

Brook Trout Sampling and Analyses

Fish populations were sampled in August and October 2014 at both the high and low wood sites via electrofishing, to obtain population estimates. Approximately 30 Brook Trout *Salvelinus fontinalis* (when available) were collected from each site for growth and diet analyses. Average growth rates were estimated from otolith (or "ear bone") sections. These structures create rings similar to tree rings and when measured, can give useful estimates of annual individual growth. Average growth rates were then estimated and compared using von Bertalanffy growth curves.

Diet samples were collected from the same 30 fish at each site and date. Diet compositions were analyzed using a multivariate community statistical approach. The proportions of insects consumed at each site and date were compared, and differences in these proportions between sites were used to determine how similar diet compositions were.

Local- vs. Landscape- scale

The above analyses provided habitat, or local, scale estimates (m^{-2}). To account for the large difference in stream area among study sites and allow results to be examined on a landscape scale, per square meter estimates were multiplied by total habitat area and divided by stream valley length (Table 1; linear m valley^{-1}).

Results

Trout biomass estimates were approximately four times higher at the high wood site, on the square meter scale, and approximately nine times higher on the valley scale (Figure 1). Average growth rates were almost identical for the two sites; however, Brook Trout in Glacier Creek reach an estimated larger overall length by approximately three-quarters of an inch (Figure 2). Diets differed between the high and low wood site during the summer (average difference = 81.09; Figure 3), but were more similar during the fall (Figure 4). Differences in the summer diets were explained by Brook Trout consuming a high proportion of ants at the low wood site (Table 2). Brook Trout at the high wood site consumed far more midge larvae during the summer than those at the low wood site (Table 2). Brook Trout at the low wood site consumed more stone fly nymphs, water mites, and assorted wasps and bees than those at the high wood site (Table 2). In general, during the summer, fish at the low wood site had higher proportions of terrestrial insects and water mites while fish at the higher wood site consumed a higher proportion of smaller aquatic benthic invertebrates and these taxa explained over 90% of the differences in diet (Table 2).

Table 2. Results from a procedure comparing the relative abundance of various insect taxa in fish diets at the low and high wood sites during summer 2014. Contributions to overall difference in diets by each taxa are indicated (Contrib %) and cumulative percentage (Cumulative %).

Species	**Common Name**	**Low Wood Abundance**	**High Wood Abundance**	**Contribution%**	**Cumulative %**
Formicidae	Ants	38.16	22.4	21.67	21.67
Chironimidae	Midge Larvae	0.35	33.77	20.62	42.29
Perlidae	Stonefly Nymph	19.18	5.89	12.74	55.03
Acari	Water Mites	14.29	0	8.81	63.84
Hymenoptera	Wasps, Bees, and Ants	10.09	2.6	7.35	71.19
Heptageniidae	Mayfly Nymph	4.86	5.28	5.2	76.39
Chalcidoidea	Chalcid Wasps	0.5	7.33	4.58	80.96
Ephemerellidae	Mayfly Nymph	0.92	5.91	3.88	84.84
Baetidae	Mayfly Nymph	3.96	4.89	3.6	88.44
Simuliidae	Black Fly Larvae	0.13	4.12	2.55	90.99

Discussion

Brook Trout biomass was significantly higher at the high wood site at both the square meter and valley scale. It is believed that instream wood has a strong effect on Brook Trout density due to the creation of low velocity habitat. At the high wood site, the high volume of large wood forced the creation of multiple parallel stream channels, creating additional aquatic habitat that is not present at the low wood site. Other research being conducted on stream benthic invertebrates suggests that large wood increases aquatic insect production that probably also influences fish population density.

The similarity of growth rates between the two sites suggests there is a higher availability of prey resources at the high wood site that allows fish to maintain high growth rates despite higher densities. Therefore, average fish size is similar at both sites. Diet data indicate the invertebrate taxa differed significantly between the high and low wood sites during the summer season. Brook Trout at the low wood site consumed more terrestrial taxa, particularly ants, and riffle species, such as stone flies. Brook Trout at the high wood site consumed more midge larvae. The preponderance of midge larvae in the high wood diets is predictable because of the high proportion of low velocity pool habitat that Chironomids prefer. Most likely, Brook Trout are keying in on the increased production of smaller benthic invertebrate species. Brook Trout at the high wood site may also consume midge larvae because there are fewer drifting insects due to higher competition. Previous research has shown that stream-dwelling salmonids are may switch to benthic-foraging (preying on aquatic invertebrates on the stream bottom) when drifting insect biomass (terrestrial and some larger aquatic invertebrates in the water column) is reduced below a certain threshold.

In this research study, the small amount of true old growth forest (> 350 years old) still remaining in the Colorado Front Range (United States) were utilized to understand how mountain headwater streams in the western United States functioned pre-European colonization. For this project, animal responses to instream wood were examined between two streams with varying riparian forest stand ages (~120 and >350 years old) and logjams densities. Trout biomass was significantly greater in our high wood site. Average growth rates, however, were very similar among sites in spite of the large differences in population densities, suggesting a higher availability of prey resources afforded by the higher habitat complexity at the high wood site. While diet data showed that trout at both sites are consuming different insects to support population densities and growth rates. Ultimately, the ecosystem-level approach provided the opportunity to examine how legacy effects are influencing mountain stream communities through both fluvial geomorphic processes (e.g., influence of logjams on the physical habitat template) and food web dynamics.

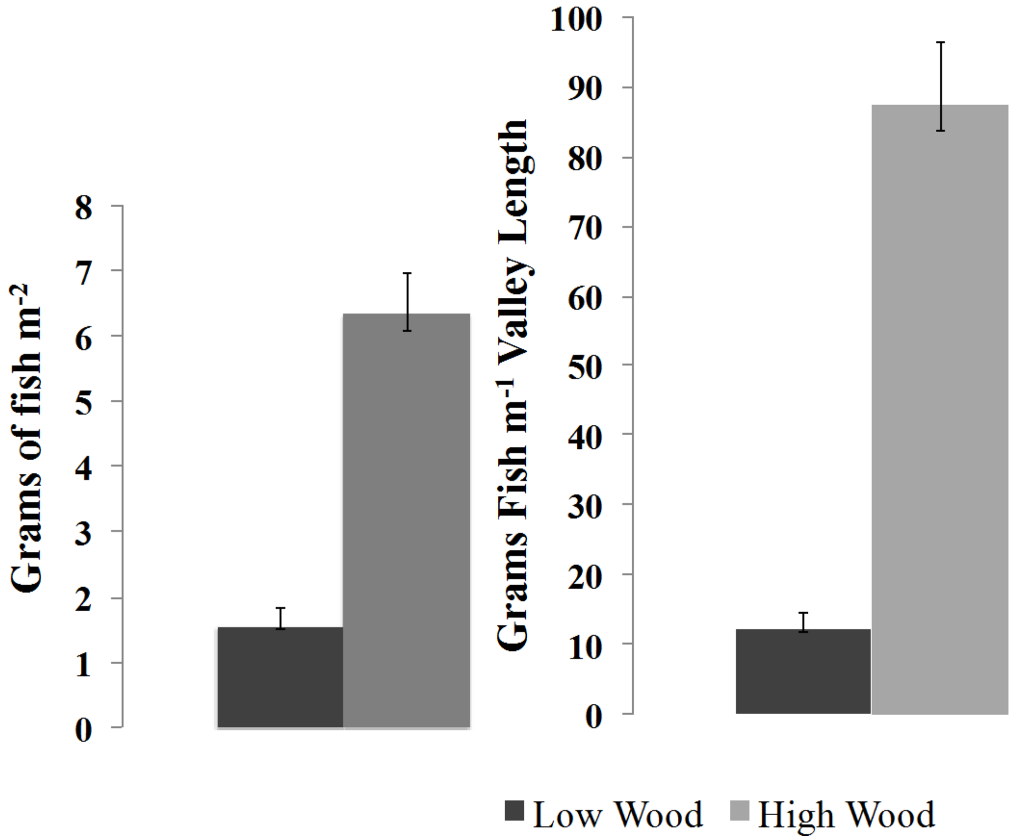


Figure 1. Biomass of fish at the low and high wood sites for summer 2014. The figure on the left shows grams of fish per square meter (local scale), while the figure on the right shows grams of fish per meter of valley length (landscape scale). At the high wood site, there is about 4 times more fish biomass at the local scale and nine times more at the landscape scale.

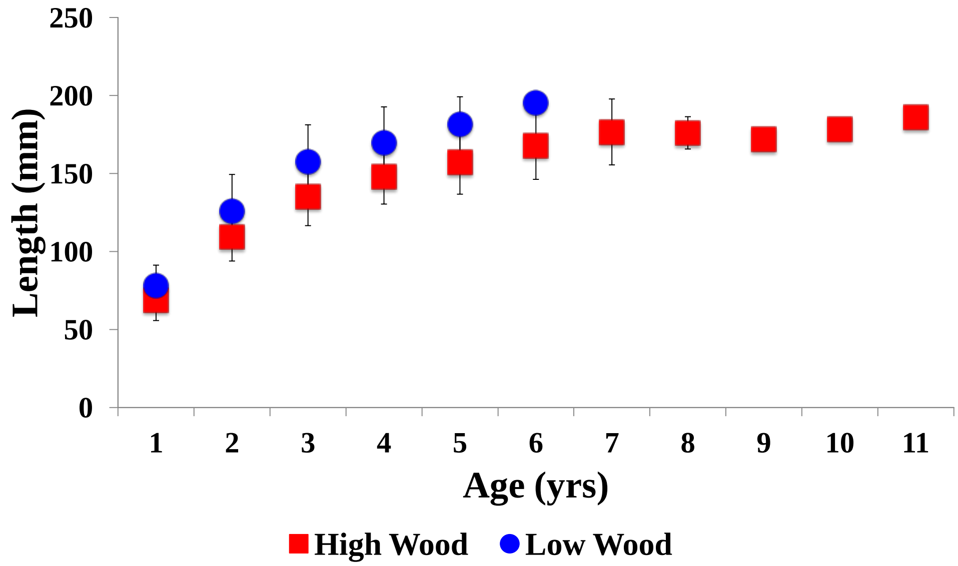


Figure 2. Average length at age for brook trout from the high wood and low wood sites. Lengths at ages are very similar for both sites, indicating similar growth rates at both sites.

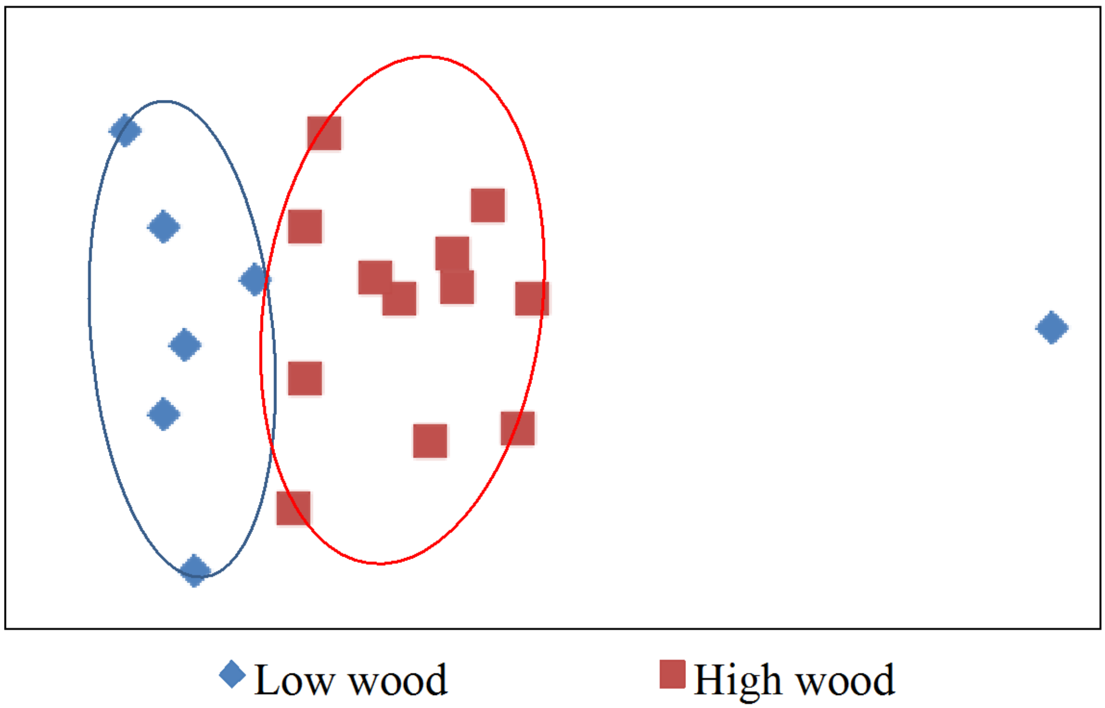


Figure 2. A two dimensional representation of diet compositions at the high and low wood sites during summer 2014. The diets form two distinct groups due to differences in prey consumed. The difference occurs because of higher consumption of small aquatic invertebrate larvae at the high wood site.

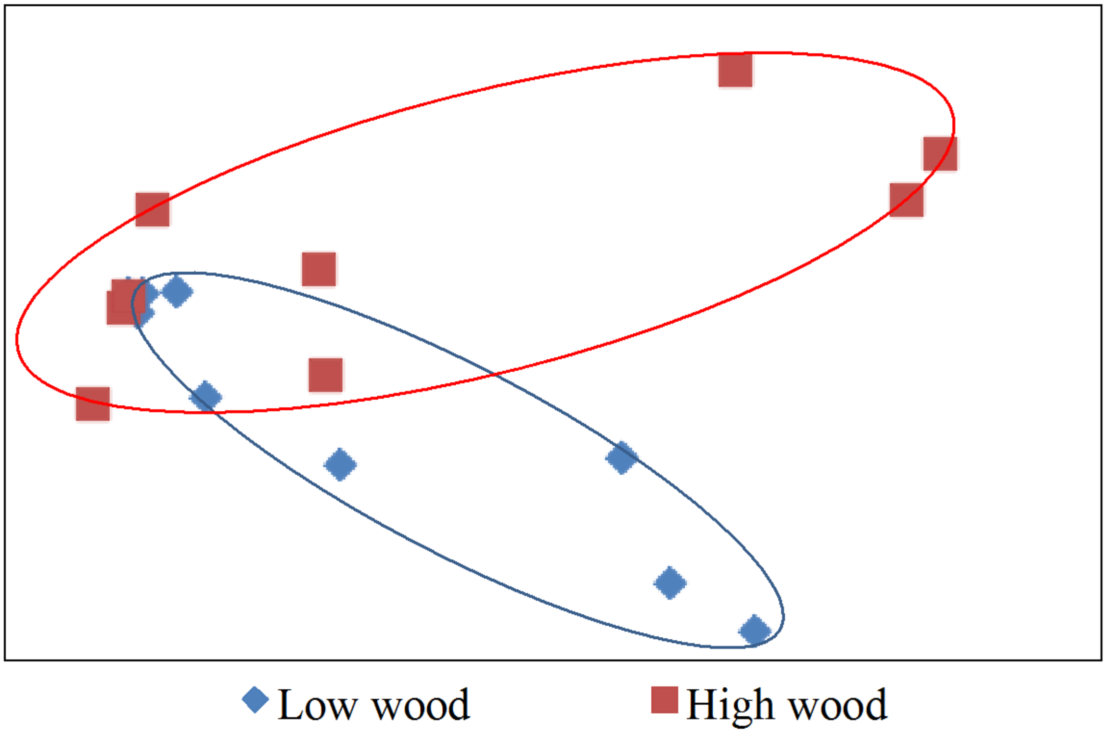


Figure 3. A two dimensional representation of diet compositions at the high and low wood sites during fall 2014. The two groups overlap because the diets are more similar during the fall sampling period compared to the spring

Trace Organic Contaminants (TOrCs) in Urban Stormwater and Performance of Urban Bioretention Systems: a Field and Modeling Study

Basic Information

Title:	Trace Organic Contaminants (TOrCs) in Urban Stormwater and Performance of Urban Bioretention Systems: a Field and Modeling Study
Project Number:	2015CO316G
USGS Grant Number:	
Start Date:	9/1/2015
End Date:	8/31/2018
Funding Source:	104G
Congressional District:	CO07
Research Category:	Water Quality
Focus Category:	Hydrology, Water Quality, Non Point Pollution
Descriptors:	None
Principal Investigators:	Christopher Paul Higgins, Edward T Furlong, Terri Hogue, John E. McCray

Publications

There are no publications.

NIWR Research Progress Report: Trace Organic Contaminants (TOrCs) in Urban Stormwater and Performance of Urban Bioretention Systems: a Field and Monitoring Study

Project Participants: Christopher Higgins (PI, Colorado School of Mines), Aniela Burant (Post-Doctoral Researcher, Colorado School of Mines), Edward Furlong (Co-PI, U.S. Geological Survey), William R. Selbig (Co-PI, Wisconsin Water Science Center), Terri S. Hogue (Co-PI, Colorado School of Mines), John E. McCray (Co-PI, CSM), Kathryn Lowe (Colorado School of Mines).

Introduction

Previous research on chemical contaminants in stormwater has focused on the occurrence and fate of compounds regulated under the Clean Water Act (e.g., metals, polycyclic aromatic hydrocarbons, nutrients). More recently, new research has identified new types of organic chemical contaminants in stormwater, including: biocides, rubber additives, flame retardants, and perfluorinated compounds. Most research is still focused on identifying hydrophobic contaminants, not polar organic compounds. In addition, little research has attributed organic contaminants to land use. Determining sources and relative loads of organic contaminants in stormwater will help inform policymakers in determining total maximum daily loads for certain trace organic contaminants in stormwater, and help inform engineering decisions related to treatment of stormwater. This data will inform improvements to the EPA Sustain and WinSLAMM models, which are designed to predict loadings to receiving bodies of water.

Another research objective is focused on evaluating bioretention of trace organic contaminants. Much research has focused on evaluating removal rates of hydrophobic organic compounds such as polycyclic aromatic hydrocarbons, however there is comparatively less data on trace polar organic contaminants, such as pesticides. This project aims to evaluate influent and effluent concentrations of both hydrophobic and hydrophilic compounds. This data will help inform policymakers in determining of total maximum daily loads of certain trace organic contaminants in stormwater, and help inform engineering decisions related to treatment of stormwater. This data will inform improvements to the EPA Sustain and WinSLAMM models, which are designed to predict loadings to receiving bodies of water.

Research Objectives

1. Identify sources, levels, and occurrences of TOrCs in urban environments.
2. Evaluate the removal of both hydrophobic and hydrophilic TOrCs in bioretention systems.
3. Evaluate existing stormwater models for predicting loadings to receiving bodies of water

Hypotheses

H1: There will be strong relationships between specific classes of TOrCs in stormwater associated with specific land uses types [with exceptions].
H2: Bioretention systems will effectively remove hydrophobic TOrCs (>90% removal), but will be less effective for polar TOrCs.
H3: Load sampling will help identify data model gaps.

Study Area

Two field sites have been secured related to Objective 1 for evaluation in Year one. Both are located in Madison, Wisconsin. One field site is considered a high-density residential site and the other one is a commercial strip mall site. Both have large percentages of impervious surface, and will produce significant volumes of runoff.

Methods

Samples are being collected with an ISCO auto-sampler, and flow-weight composited, which will allow for event mean concentrations of TOrCs in the stormwater to be obtained. The samples are filtered to remove particulate matter. Mass-labelled surrogates are spiked in and the organic compounds from the dissolved phase are extracted via solid phase extraction, using Oasis HLB cartridges, and the TOrCs are eluted from the cartridges using methanol. The extracts are evaporated to 0.5 mL, and reconstituted to 2 mLs using methanol. The extracts are then analyzed by using liquidchromatography coupled with tandem mass-spectrometry in both positive and negative electrospray ionization mode. Targeted TOrCs include: a variety of different pesticides and transformation products, flame retardants, and corrosion inhibitors. The extracts will also be analyzed by liquidchromatography coupled with quadrupole time-of-flight for suspect screening of organic contaminants.

Other samples are collected and are sent to the USGS' National Water Quality Lab. The method to be used targets wastewater indicator compounds, which are extracted by liquid-liquid extraction using dichloromethane. These samples are then analyzed by gas-chromatography coupled with mass spectrometry.

Preliminary Results and Achievements in the First Year

This project has been recently funded. A literature review of trace organic contaminants in stormwater is being conducted. A detailed work plan with identification of critical parameters and methodologies needed for assessment has been developed. Sampling for storm events on the high density residential site has started. Water samples from three storms, and a dry-weather flow have been collected, and processed. Samples for the first event have been analyzed, and 22 of the 26 trace organic contaminants in the LC method had detectable limits of the TOrCs. Sampling and analysis is still on-going. It is expected that sampling for the commercial strip area will begin in mid-May. Due to the early nature of the project, there are not any notable awards or achievements, journal papers, or conference presentations to report (to date – please note a planned conference presentation for this coming summer). The direct and regular communication with U.S. Geological Survey (both Selbig and Furlong) has already yielded significant benefits to both parties with respect to information transfer. At present, no graduate students have been supported on the project, but we anticipate this to change within the coming year. In addition, we are seeking opportunities to provide student training through student internship programs.

Future Conference Presentations

A poster presentation is scheduled for the end of June at the Gordon Research Conference on Environmental Science: Water, titled “Correlating organic contaminants in stormwater with land use.”

Application of Remotely Sensed Data for Improved Regional and National Hydrologic Simulations

Basic Information

Title:	Application of Remotely Sensed Data for Improved Regional and National Hydrologic Simulations
Project Number:	2015CO331S
USGS Grant Number:	
Sponsoring Agency:	U.S. Geological Survey
Start Date:	4/15/2015
End Date:	2/15/2016
Funding Source:	104S
Congressional District:	
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Terri Hogue

Publications

There are no publications.

Application of Remotely Sensed Data for Improved Regional and National Hydrologic Simulations

NIWR Progress Report-2015CO331S

FUND #5311002

Reporting period March 1, 2015 – February 29, 2016 (~Year 2)

PI: Terri S. Hogue
Colorado School of Mines
1500 Illinois Street
Civil and Environmental Engineering
CO232 Coolbaugh Hall
Golden, CO 80401

Collaborators: Lauren Hay, Steven Markstrom and R. Steve Regan
United States Geological Survey, Lakewood, CO, USA

1. Project Overview

The overarching goal of this CSM-USGS collaborative project was to improve hydrologic modeling of the contiguous United States (CONUS) using remotely sensed data products (RSDPs) from the USGS EROS center as well as those being developed through research led by PI Dr. Terri Hogue. The proposed research for this scope of work originally focused on estimates of growing season within the Precipitation Runoff Modeling System (PRMS) based on remotely sensed phenology products (Year 1). Year 2, which included a funded extension, also included analysis and application of remote sensing and other spatial data to parameterize burned watersheds within the PRMS national model. This also included understanding the geophysical parameters driving change and then using that information for parameterizing PRMS for post-fire watersheds. This research opportunity was used to facilitate research through the Colorado Water Resources Research Institute and the USGS National Research Program to explore the application and improvement of PRMS in western Watersheds. This particular application of PRMS is the National Hydrologic Model (NHM) which is delineated into ~110,000 sub-basins (defined as hydrologic response units) based on aggregated NHDPlus (http://www.horizon-systems.com/nhdplus/) catchments for the CONUS

Growing Season RSDPs

PRMS sets the period of active transpiration (growing season) using three methods: 1) frost; 2) temperature index; and 3) dynamic specification. The frost method defines the growing season based on the average first and last freezing air temperatures for each hydrologic response unit (HRU) based on the method described by the U.S. Army Corps of Engineers (1987). The growing season is fixed for the simulation time period. The temperature index approach defines the growing season based on a temperature threshold for a specified begin and end month. Once the sum of the daily maximum air temperature exceeds the threshold within the begin month for a HRU, transpiration is active. Transpiration is inactive on the first day of the end month. The dynamic specification method provides a means to change transpiration state on any day of a simulation time period with the initial transpiration state established using either the frost or temperature index method. The USGS/EROS Center product (http://phenology.cr.usgs.gov/) derives phenological metrics such as start and end of growing season by using inflection points in a smoothed timeseries of normalized difference vegetation index (NDVI) from the Advanced Very High Resolution Radiometer (AVHRR).

Post-fire Watershed Modeling

Work has focused on investigation of the impact of wildfires on watershed flow regimes throughout the western United States as well as parameterization of the PRMS for post-fire systems. Information on fire events and watershed characteristics were collected through federal and state-level databases and streamflow data were collected from U.S. Geological Survey stream gages. 82 watersheds were identified with at least 10 years of continuous pre-fire daily streamflow records and 5 years of continuous post-fire daily flow records. Statistics, clustering and analysis of response related to watershed characteristics and geophysical parameters was undertaken for all watersheds.

Six watersheds were then selected for model investigations using the Precipitation Runoff Modeling System (PRMS), a distributed-parameter, physical process based watershed model. Two change detection modeling approaches are applied in order to better understand post-fire changes and their related processes. First, the model was used to determine if each watershed shows significant changes in flow regimes following each wildfire. Second, post-fire parameterization was examined using a generalized likelihood uncertainty estimation (GLUE) approach and a national-scale sensitivity analysis. Evapotranspiration products from remote sensing platforms were also analyzed for use in post-fire characterization.

2. Completed Tasks

Growing Season RSDPs

This phase was successfully completed by defining two RSDP derived growing season parameter sets (fixed and dynamic) for each hydrologic response unit in the NHM for water years 1990 to 2010. The fixed RSDP growing season is derived for each HRU by calculating long-term (1990-2010) average annual growing season dates which are then fixed for the deration of the simulation period, while the dynamic parameter set defines a growing season for each individual year. Using the NHM, modeled hydrologic outputs were produced using default model parameters and the two RSDP derived parameter sets. Spatial and temporal anomalies of model outputs such as actual evapotranspiration (AET; Figure 1), surface runoff, interflow, and groundwater flow (baseflow) were then compared between model runs with the default parameter set and the RSDP dataset. Results show anomalies in AET and the components of flow vary geographically. Spatial anomalies were also shown to be correlated to land cover type. The temporal analysis showed that AET anomalies are variable through time depending on the

RSP defined growing season period, and the monthly analysis showed that the largest differences were apparent in the winter and shoulder seasons. The largest anomalies are apparent in the Rocky Mountain west, where the baseline model produces less AET and more baseflow compared to the model ran with the RSP growing season. Annual differences in AET can reach up 10 inches in certain HRUs which may have significant implications for the annual water balance in those areas.

Post-fire Watershed Modeling

For each watershed, percent changes in annual runoff ratio (RO), low-flows (LF), high-flows (HF), peak flows (PF), number of zero flow days (Nzeros), baseflow index (BFI), and Richards-Baker flashiness index (RB) were calculated for both pre- and post-fire periods. The national watersheds were divided into five regions through k-means clustering and regression models were produced for watersheds grouped by total area burned. The coefficient of determination (R^2) was used to determine the accuracy of the resulting models. Analysis of changes to flow regimes indicate that post-fire response is greatest in the 1st year following wildfire and decreases over time. Overall, post-fire changes are highly variable, but typically show an increase across all flow regimes investigated in this study.

For the PRMS modeling investigations, the six watersheds showed significant increases in the difference between observed and modeled daily streamflow following the wildfire. For these watersheds, the parameterization analysis using PRMS revealed that changes in immediate surface runoff processes are best represented through preferential flow and imperviousness, and changes in evapotranspiration should be represented through soil zone capacities. The national-scale investigation into post-fire ET parameterization provided valuable insight into the relationship between post-fire vegetation changes and ET, both in the model and in the real world. There is opportunity for future analysis to more specifically relate post-fire vegetation changes to ET. Combined with the results of the ET sensitivity analysis, this information can inform how to best incorporate post-fire vegetation changes into the model in a way that accurately accounts for changes in ET, and thus help improve the model's applicability to disturbance and land-cover change studies.

3. Notable awards and achievements

2 M.S. Thesis completed at CSM:

Sam Saxe, January 2016:

Ryan Logan, June 2016:

1 M.S. Non-thesis completed at CSM:

Paul Micheletty, May 2014

4. Journal papers

Micheletty, P. T.S. Hogue, L. Hay, S. Markstrom, R. Regan, 2016: Integration of Satellite-Based Phenology Products into USGS National Hydrologic Model, *in preparation*

Saxe, Samuel W, Terri S. Hogue, and Lauren Hay, 2016: Evaluation and Characterization of Changes in Post-fire Streamflow Response, *in preparation*

Logan, R., T.S. Hogue and L. Hay, 2016: Modeling wildfire impact on hydrologic processes using the Precipitation Runoff Modeling System, *in preparation*

Saxe, Samuel W, Terri S. Hogue, and Lauren Hay, 2016: Regional Drivers of Post-fire Streamflow Response for Western U.S. Watersheds, *in preparation*

5. Conference presentations

Micheletty, P. T.S. Hogue, L. Hay, S. Markstrom, R. Regan, 2014: Improving USGS National Hydrologic Model Parameterization with Satellite-Based Phenology Products, AGU Fall Annual Meeting, December, 2014

Saxe, S. T.S. Hogue and L. Hay, 2015: Regional Variability of Controls on Post-Wildfire Watershed Flow, American Geophysical Union: Hydrology Days, Fort Collins, March, 2015.

Hogue, T.S., 2015: Forest and land cover change: Improving predictions of hydrologic response through advances in remote sensing, Third Workshop on Water Resources in Developing Countries: Planning and Management in Face of Hydroclimatological Extremes and Variability, International Center for Theoretical Physics, Trieste, Italy, April 2015 *(Invited Presentation*).

Saxe, S., T.S. Hogue and L. Hay, 2015: Linear Modeling and Evaluation of Controls on Flow Response in Western Post-Fire Watersheds, AGU Fall National Meeting, San Francisco, CA. December 2015.

Logan, R., T.S. Hogue and L. Hay, 2015: Modeling wildfire impact on hydrologic processes using the Precipitation Runoff Modeling System, AGU Fall National Meeting, San Francisco, CA. December 2015.

6. Information transfer

All research activities are in direct collaboration with the MOWS group at the federal center led by Lauren Hay. Results and information are being directly integrated into the National Model through the PRMS model. We also are have been presenting results at regional and national meetings and we are in the process of producing manuscripts for publication in peer-reviewed journals.

7. Student support

Support through this funding has been provided for an M.S. student – Paul Micheletty, who then transitioned to a research hourly worker on the project through August 2015. Funds were also used to provide support for Samuel Saxe as a research hourly worker from February 2016 forward.

8. Student internship programs

Two student internships were also integrated within this project – Sam Saxe (M.S. student) and Ryan Logan (M.S. student).

Information Transfer Program Introduction

Requests from the Colorado legislature and key water agencies to facilitate and inform basin-level discussions of water resources and the state water plan emphasized the role Colorado Water Institute plays in providing a nexus of information. Some major technology transfer efforts this year include:

- Providing training for Extension staff in various water basins to help facilitate discussions of water resources
- Encouraging interaction and discussion of issues between water managers, policy makers, legislators, and researchers at conferences and workshops
- Publishing the bi-monthly newsletter, which emphasizes water research and current water issues
- Posting and distributing all previously published CWI reports to the web for easier access
- Working with land grant universities and water institutes in the intermountain West to connect university research with information needs of Western Water Council, Family Farm Alliance, and other stakeholder groups
- Working closely with the Colorado Water Congress, Colorado Foundation for Water Education, USDA-NIFA funded National Water Program to provide educational programs to address identified needs

Technology Transfer and Information Dissemination

Basic Information

Title:	Technology Transfer and Information Dissemination
Project Number:	2015CO307B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Reagan M. Waskom

Publications

1. Colorado Water Newsletter, Volume 32 – Issue 2 (May/June 2015), Colorado Water Institute, Colorado State University, Fort Collins Colorado, 40 pages.
2. Colorado Water Newsletter, Volume 32 – Issue 3 (July/August 2015), Colorado Water Institute, Colorado State University, Fort Collins Colorado, 40 pages.
3. Colorado Water Newsletter, Volume 32 – Issue 4 (November/December 2015), Colorado Water Institute, Colorado State University, Fort Collins Colorado, 40 pages.
4. Associated Sponsors. October 26, 2015. Growing Forward: Preceedings from the 26th Annual South Platte Forum. Colorado Water Institute, Colorado State University, Fort Collins, CO. 25 pages. http://cwi.colostate.edu/publications/IS/118.pdf
5. Brown. Jennifer. October 26, 2015. Water and Wisdom: Preceedings from the 25th Annual South Platte Forum. Colorado Water Institute, Colorado State University, Fort Collins, CO. 30 pages. http://cwi.colostate.edu/publications/IS/117.pdf
6. Waskom, Reagan, Rein, Kevin, Wolfe, Dick, Smith MaryLou. February 16, 2016. How Diversion and Beneficial Use of Water Affect the Value and Measure of a Water Right. Colorado Water Institute, Colorado State University, Fort Collins, CO. 15 pages. http://cwi.colostate.edu/publications/SR/25.pdf

Colorado Water Institute Activities

- Interdisciplinary Water Resources Seminar, Spring 2015
- Exploring Jobs, Careers and Leadership in Water Resources, GRAD592, Fall 2015
- *Colorado Water*, Colorado Water Institute, March 2015 – February 2016
- CSU MOOC *Water, Civilization, and Nature: Addressing 21st Century Water Challenges*
- CSU Water Experts, cwi.colostate.edu/CSUWaterExperts/default.aspx
- CSU Hydrology Days, March 23 – 25, 2015
- *Deadbeat Dams* presentation and book signing by author Dan Beard, March 24, 2015
- 7th World Water Forum, CSU delegation attended, April 12 – 17, 2015
- Fort Collins Poudre RiverFest, May 2015
- Water Archives Western Water Symposium, July 27, 2015
- Best Practices for Collaborative Water Decisions: Moving from Concept to Action, October 14-16, 2015
- 3rd Annual Poudre River Forum, February 5, 2016
- Water Tables 2016, January 28, 2016
- Host Senior Fellow, Dr. John Matthews

Spring Water Seminar 2015

Mondays from 4:00 to 5:00 PM

January 26
LSC Room 322

Brad Udall, Senior Water and Climate Scientist, Colorado Water Institute
The Colorado River Structural Deficit: Why it Matters to Colorado

February 2
LSC Room 322

Ashley Anderson, Assistant Professor, Department of Journalism and Technical Communication
Floods, Communication, and Climate Change: Exploring the Role of Media Use and Interpersonal Discussion in Connecting Water-Related Extreme Weather Events to Perceptions about Climate Change

February 9
LSC Room 322

Sybil Sharvelle, Associate Professor, Department of Civil & Environmental Engineering
Evaluation of Urban Nutrient Loading and Recommendations for Cost Effective Treatment Technologies

February 16
LSC Room 308-10

Reagan Waskom, Director, Colorado Water Institute
State of the CSU Water Center & Faculty Listening Session

February 23
LSC Room 322

Tim Covino, Assistant Professor of Watershed Science Department of Ecosystem Science & Sustainability
Loss of Catchment Retention: Interactions between Catchment Morphology, Residence Time, and Geochemical Processing Amidst a Changing Hydrologic Regime

March 2
Room 322

Ed Hall, USGS Research Biologist, Natural Resource Ecology Laboratory
Across the Aquatic-Terrestrial Interface: Understanding the Hydro-Bio-Geo-Chemistry of Extreme Events

March 9
LSC Room 322

Jessica Davis, Professor, Department of Soil and Crop Sciences
Joshua Wenz, Graduate Student
The Water-Nitrogen Tradeoff: Optimizing the Use of Water to Fix N and Reduce Agriculture's C Footprint

March 30
LSC Room 308-10

Ryan Bailey, Assistant Professor, Department of Civil & Environmental Engineering
Developing a Framework for Simulating the Fate and Transport of Salinity Species in the Lower Arkansas River Valley, Colorado

April 6
LSC Room 322

Jay Ham, Professor of Environmental Physics, Department of Soil and Crop Sciences
New Technology for Measuring Sap Flow and Transpiration in Agricultural and Native Ecosystems

April 13
LSC Room 322

Stephanie Malin, Assistant Professor, Department of Sociology
When Water Rights Ebb into Energy Development: Unconventional Oil & Gas Development and Changes to Water Allocation in Northern Colorado

April 20
LSC Room 322

Dana Winkelman, Unit Leader, U.S. Geological Survey Colorado Cooperative Fish and Wildlife Research Unit
Rocky Mountain Streams Past and Present: The Influence of Forest Stand Age and Wood Deposition on Trout and Insect Biomas

April 27
LSC Room 322

Yan Vivian Li, Assistant Professor in Textile Science, Department of Design and Merchandising
William Sanford, Associate Professor, Department of Geosciences
How Carbongenic Nanoparticles (Cnps) Move Through Various Types of Porous Media Under Conditions that Replicate the Natural Environment

May 4
LSC Room 312

Stacy Lynn, Research Scientist, Natural Resource Ecology Laboratory
From Water Scarce to Water Source: The Governance of New Water in the Kenyan Drylands

Sponsored by: CSU Water Center, USDA-ARS, Civil and Environmental Engineering, and Forest and Rangeland Stewardship.
All interested faculty, students, and guests are encouraged to attend.
For more information, contact Reagan Waskom at reagan.waskom@colostate.edu or visit watercenter.colostate.edu

Interdisciplinary Water Resources Seminar GRAD592

Mondays 4:00 – 5:00 PM,
NATRS Room 109

Fall 2015 Theme:
Exploring Jobs, Careers and Leadership in Water Resources

The purpose of the 2015 Interdisciplinary Water Resources Seminar (GRAD592) is to expose students to the broad gamut of opportunities and trends within the field of water resources through guest lectures by prominent Colorado water practitioners.

More specifically, the seminar will:
1. Examine jobs and careers in the international, government, private and NGO sectors
2. Discuss how students can best prepare for water jobs and careers
3. Examine the trends and future of various sectors of the industry
4. Discuss leadership in the water resources professions

Students interested in taking the one-credit seminar should sign up for GRAD592, Water Resources Seminar, CRN 74006. The seminar will be held at 4:00pm Monday afternoons in **NATRS Room 109.** (Students who have enrolled in GRAD592 in the past may also enroll for this offering.)

Seminar Organizers: Ryan Bailey, Troy Bauder, John Stednick, Pete Taylor, and Reagan Waskom.

Aug 24	CSU Career Center	*Introductions, expectations, and a short presentation*
Aug 31	Michael Lewis, US Geological Survey	
Sept 7	No Class	*Labor Day*
Sept 14	Alex Davis, Aurora Water	
Sept 21	Taylor Hawes, The Nature Conservancy	
Sept 28	Ayn Schmidt & Karen Hamilton, US EPA Region 8	
Oct 5	Brad Wind, Northern Colorado Water Conservancy District	
Oct 12	Erin Wilson, Wilson Water Group	
Oct 19	Liv Haugen, CH2M Hill	
Oct 26	Dave Holm, Clear Creek Watershed Association	
Nov 2	Marc Waage, Denver Water	
Nov 9	Carl Chambers, US Forest Service	
Nov 16	David Ellerbroek, AECOM	
Nov 23	No Class	*Fall Break*
Nov 30	Chris Lidstone, Lidstone and Associates, Inc.	
Dec 7	Presentations	*Students*

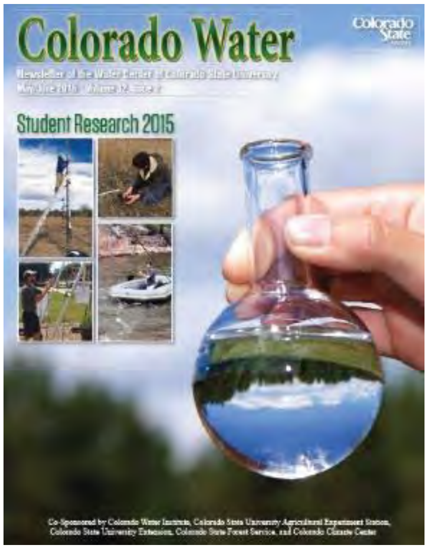
All interested faculty, students, and off-campus guests are encouraged to attend.

For more information, contact Reagan Waskom at reagan.waskom@colostate.edu or visit watercenter.colostate.edu

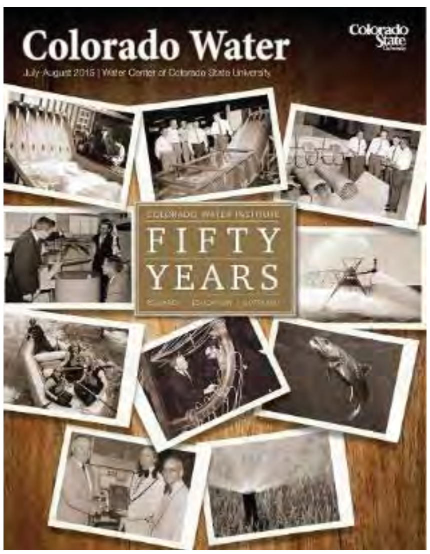
Colorado Water Institute

Colorado State University

CSU WATER CENTER



Colorado Water
Volume 32, Issue 2
Student Research 2015



Colorado Water
Volume 32, Issue 3
Fiftieth Anniversary

Colorado Water
Volume 32, Issue 4
Agricultural Water Conservation

Water MOOC

For the past two years, The CSU Water Center has partnered with CSU Online and CSU's Institute for Learning and Teaching (TILT) to develop a Massive Open Online Course, popularly known as a MOOC. MOOCs are noncredit, student-interaction-based programs that provide educational access to the public at no cost. They are typically less immersive than credit courses you would find at a university, offering more generalized content that is meant to provide you with a breadth of understanding across the subject matter. MOOCs feature instructor-driven content with a heavy emphasis on student participation. This student-to-student communication creates knowledge and discoveries that enrich the course with a social aspect and shared experiences.

Water, Civilization, and Nature: Addressing Water Challenges of the 21st Century

Recent water issues, increasing populations worldwide, and variations in climate have impacted our water supply, creating questions and issues we have never been challenged with before. This free online course offers an in-depth look at these issues guided by Colorado State University, a leader in water science and studies. The course is taught by more than 10 expert Colorado State water faculty, and is especially valuable for those interested in the fields of:

- Water
- Civil engineering
- Conservation
- Public health
- Fishery/wildlife
- Agriculture
- Governance and conflicts related to water

View the course lectures from the 2015 MOOC:

More Information

- Complete Playlist of Faculty Lectures on YouTube
- 2015 Course Syllabus
- Stay up to date by visiting the course's Facebook page

CSU WATER EXPERTS

CSU WATER CENTER

Colorado State University

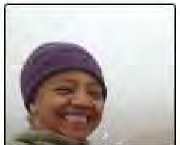
By Name A B C D E F G H I J K L M N O P Q R S T U V W X Y Z (View all)

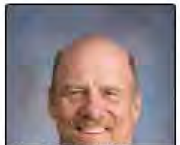
By Department

(select a department)

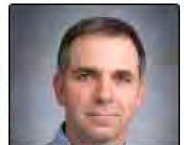
By Expertise

- (View all)
- Agriculture
- Anthropology, History, and Sociology
- Aquatic, Wildlife, and Forest Ecology
- Business
- Chemistry
- Climate Science
- Ecosystem Dynamics
- Education and Outreach
- Energy
- Environmental Engineering
- Fisheries Biology
- Fluvial Geomorphology and Sediment Transport
- Geosciences
- Groundwater
- Horticulture and Landscape
- Hydraulics
- Hydrology
- Irrigation and Drainage
- Library Materials
- Limnology
- Management and Planning
- Models, GIS, and Data
- Recreational Resources
- Remote Sensing
- Resource Economics
- Snow and Glaciers
- Soil Science
- Streams, Riparian Zones, and Wetlands
- Toxicology and Microbiology
- Water and Waste Water Treatment
- Water Conservation
- Water Policy
- Water Quality
- Watershed Restoration and Management
- Wildlands Hydrology

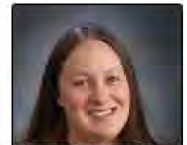

Gillian Bowser, PhD
Research Scientist and Scholar
Natural Resource Ecology Lab
(970) 491-5871 [Email]


Alan D. Bright, PhD
Associate Professor
Human Dimensions of Natural Re...
(970) 491-5457 [Email]


Brett Bruyere, PhD
Associate Professor
Warner College of Natural Resources
(970) 491-1360 [Email]

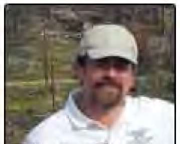

Perry E. Cabot, PhD
Research Scientist and Extension Sp
CSU Extension
(970) 434-3264 [Email]


Kenneth Carlson, PhD
Associate Professor
Civil and Environmental Enginee...
(970) 491-8336 [Email]

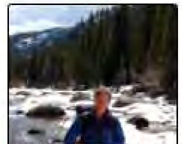

Kimberly B. Catton, PhD
Research Scientist and Scholar
Civil and Environmental Enginee...
(970) 491-3689 [Email]

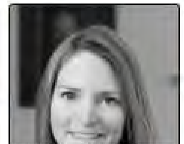

V Chandrasekar, PhD
Professor
Electrical and Computer Engineer...
(970) 491-7981 [Email]


Wayne A. Charlie, PhD
Professor
Civil and Environmental Enginee...
(970) 491-5048 [Email]

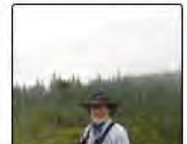

Jose L. Chavez, PhD
Assistant Professor
Civil and Environmental Enginee...
(970) 491-6095 [Email]

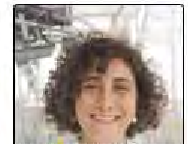

Tony Cheng, PhD
Professor
Forest and Rangeland Stewardship
(970) 491-1900 [Email]


William H. Clements, PhD
Professor
Fish, Wildlife and Conservation Bio
(970) 491-0690 [Email]

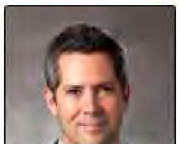

Jennifer C. Coats
Assistant Professor
Finance and Real Estate
(970) 491-0333 [Email]


Richard Conant, PhD
Professor
Natural Resource Ecology Lab
(970) 491-1919 [Email]

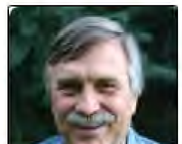

David J. Cooper, PhD
Senior Research Scientist
Forest and Rangeland Stewardship
(970) 491-5430 [Email]


Francesca Cotrufo, PhD
Professor
Soil and Crop Sciences
(970) 491-6056 [Email]

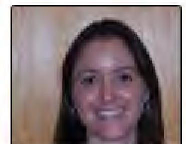

William R. Cotton, PhD
Emeritus Professor
Atmospheric Science
(970) 491-8593 [Email]

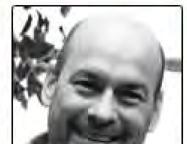

Tim Covino, PhD
Assistant Professor
Ecosystem Science and Sustainabili
(970) 491-1968 [Email]

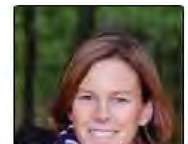
No Photo Available
Mike Culbertson
Associate Professor
Library
(970) 491-1874 [Email]

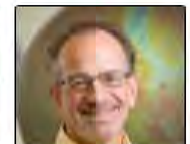

Stephen P. Davies, PhD
Emeritus Professor
Agricultural and Resource Econo...
(970) 491-6955 [Email]


Jessica G. Davis, PhD
Professor
Soil and Crop Sciences
(970) 491-1913 [Email]


Susan K. De Long, PhD
Assistant Professor
Civil and Environmental Enginee...
(970) 491-6606 [Email]


Thomas J. Dean, PhD
Professor
Business College
(970) 491-7266 [Email]


Karolien Denef, PhD
Research Scientist
Natural Resource Ecology Lab
(970) 491-5580 [Email]


A. Scott Denning, PhD
Professor
Atmospheric Science
(970) 491-8359 [Email]

PREVIOUS

NEXT

Conference Program

AGU Hydrology Days 2015

March 23 - March 25, 2015
(Download **Conference Program** in PDF format)

Program at a Glance

March 23		March 24		March 25
Registration	**8 am**	**Registration** **Posters**	**8 am**	**Registration** **Posters**
Eco-Hydrology	**9 am**	**Water Supply**		
	8:30 am	**High Park Fire**	**8:30 am**	**Poster Session**
Mid-morning break		Mid-morning break		Mid-morning break
Eco-Hydrology	**10:15 am**	**Water Supply**	**9:30 am**	**Erosion and Sedimentation**
	10:00 am	**High Park Fire**	**9:30 am**	**Latin America**
Lunch **Borland Lecture in Hydrology**	**12 - 2 pm**	**Lunch** **Hydrology Days Award Lecture**	**12 - 2 pm**	**Lunch** **Borland Lecture in Hydraulics**
Climate - Precipitation Extremes	**2 pm**	**Hydraulics - CFD**	**2 pm**	**Watershed Modeling - Model Integration**
Mid-afternoon break		Mid-afternoon break		Mid-afternoon break
Contaminant - Fate and Transport	**4 pm**	**Stream and Lake Water Quality**	**3:45 pm**	**Ungaged Basins - Urban Hydrology**
		Deadbeat Dams		
Adjourn		Adjourn		**Hydrology Days Ends**

Hydrology Days 2015 Program

Monday

Session

Registration - Cherokee Park Room - Lory Student Center

Eco-Hydrology - Interdisciplinary WATER research

Chair: Professor José L. Chávez
Department of Civil and Environmental Engineering, CSU

Cherokee Park Room - Lory Student Center

Assessment of Imjin Riverine Wetland Function Using Hydrogeomorphic Method
Seungjin Hong, Taekmin Kim, Duck Hwan Kim, Dae Gun Han, Changhyun Choi, Hung Soo Kim
Department of Civil Engineering, Inha University, Korea

Analysis of Relationship between Inundation Depth of Flow Duration and Plant Habitat
Jung Wook Kim, Dae Wung Lee, Yon Soo Kim, Seung Jin Hong, Hyung Soo Kwon, Hung Soo Kim
Department of Civil Engineering, Inha University, Korea

Estimation of sensible heat flux of a drip-irrigated vineyard using the aerodynamic temperature model in Talca-Chile
Marcos Carrasco-Benavides, Samuel Ortega-Farías, Luis Morales-Salinas and José L. Chávez
Department of Agricultural Sciences, Catholic University of Maule, Chile; E-Mail: mcarrascob@ucm.cl

Monolithic weighing lysimeter-based alfalfa evapotranspiration rates evaluation using micrometeorological instruments
Abhinaya Subedi, José L. Chávez, Allan A. Andales
Department of Civil and Environmental Engineering, Colorado State University

Evaluation of Water Stress Coefficient Methods to Estimate Actual Corn Evapotranspiration in Colorado
Emily G. Kullberg, José L. Chávez, and Kendall DeJonge
Department of Civil and Environmental Engineering, Colorado State University

Mapping evapotranspiration at high resolutions using the Surface aerodynamic temperature model and airborne multispectral remote sensing data
M. Semin Barlak, José L. Chávez, Prasanna H. Gowda, and Steven R. Evett
Department of Civil and Environmental Engineering, Colorado State University

Mid-morning break

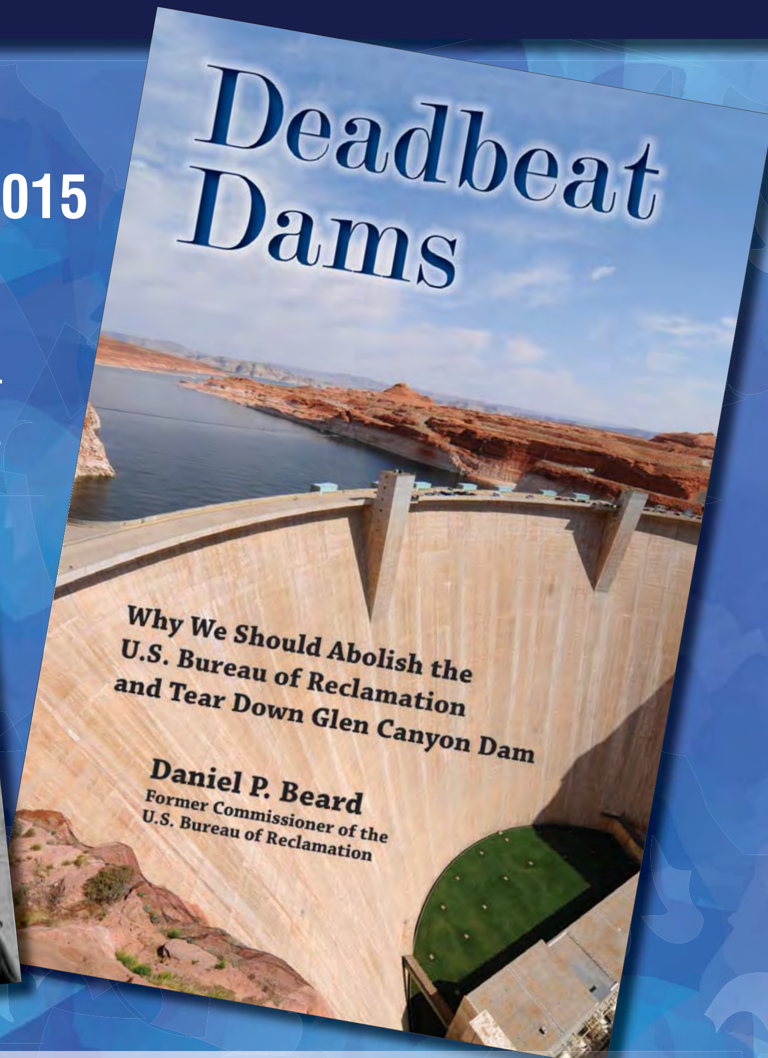
Eco-Hydrology - Interdisciplinary WATER research

Chair: Professor Jorge A. Ramirez
Department of Civil and Environmental Engineering, CSU

Cherokee Park Room - Lory Student Center

In conjunction with CSU Hydrology Days 2015 and World Water Day, The CSU Water Center Presents:

DANIEL BEARD



TIME & LOCATION:

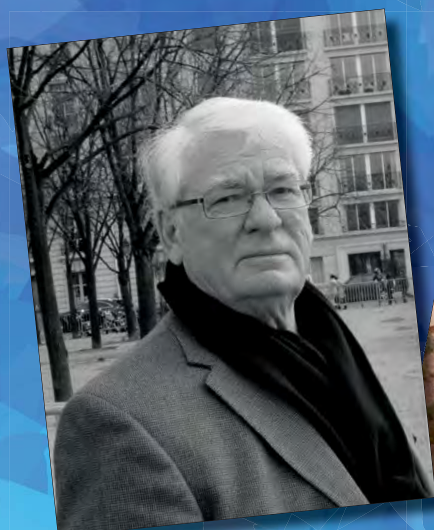
Tuesday, March 24, 2015

6:00 pm: Book Signing

6:30 pm: Presentation

Lory Student Center Theater

FREE *and open to the public*



HYDROLOGY DAYS

March 23 - March 25, 2015
Colorado State University, Fort Collins, Colorado

Hydrology Days Award Lecturer:
Scott W Tyler, University of Nevada, Reno

Borland Lecturers:
Amilcare Porporato, Duke University; Gordon Grant, Oregon State University

CSU WATER CENTER

Colorado State University

HIGHLIGHTS

Closing Ceremony

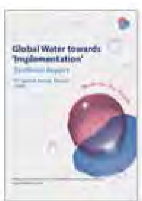
<Daegu-Gyeongbuk Implementation Commitment (DGIC) >DGIC launching at the Closing Ceremony, April 17, EXCO Daegu

Closing Ceremony

<Goodbye until 2018 Brasilia>Commemorative Photographing "Goodbye until 2018 Brasilia", April 17, EXCO Daegu

Closing Ceremony

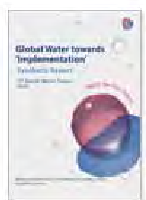
FORUM OUTCOMES



7th World Water Forum - Synthesis Report

More than three years of preparatory process ... more

DOWNLOAD



7th World Water Forum - Final Report

More than three years of preparatory process ... more

DOWNLOAD

[Thematic Process]
Thematic Process Final Report_Appendix 3_Session Reports — DOWNLOAD

[Political Process]
Ministerial Declaration (English) — DOWNLOAD

[Regional Process]
Regional Process Final Report — DOWNLOAD

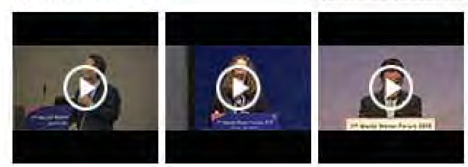
[Science & Technology Process]
Science and Technology Process Final Report — DOWNLOAD

7th World Water Forum
ACTION MONITORING SYSTEM

7th World Water Forum
PROGRAMS

FORUM VIDEOS

View all the videos



FORUM PHOTO

View all the photos

Colorado State University
MORGAN LIBRARY

Monday, July 27, 2015
10 a.m.-8 p.m.

Morning Session - Lunch - Afternoon Session - Reception - Barbecue

Justice Gregory J. Hobbs Jr.
Colorado Supreme Court Justice
Symposium emcee and moderator

Patty Limerick
History professor and chair of the board, Center of the American West, University of Colorado
"Making Peace with our Predecessors"

Pat Mulroy
Senior fellow, Boyd School of Law, Climate Adaptation and Environmental Policy, Brookings Institution
"Managing Water Resources in the Face of Uncertainty: Can We Adapt?"

Susan Schulten
History professor and department chair, University of Denver
"The Great American Desert? Pioneering Views of Colorado"

Jason Peltier
Chief deputy general manager, Westlands Water District, California
"The 'New' Values of Today Do Not Make 'Old' Values Irrelevant"

Join the Water Resources Archive for a day of learning, debate, and discussion focused on pioneering our water future.

Life in the American West has been made possible by pioneers, dreamers, and doers. People developing farms and towns created the technology, laws, and organizations that we use today to manage the limited water available in arid and semiarid Western landscapes. They left a legacy, which is the foundation for our future. What are some of those past innovations we inherited? And how do we build on those for the pioneering ideas of tomorrow?

The setting may be neutral, but the ideas will not be!

Register Today!

Best Practices for Collaborative Water Decisions

Moving from Concept to Action

Wine Country Inn
Palisade, Colorado

October 14–16, 2015

A 16-hour, highly interactive training to help water professionals, leaders, and stakeholders deepen and strengthen their skills, tools and capacity for collaboration and consensus around complex water challenges.

$995 if registered by August 31, 2015. $1,095 after August 31, 2015.

Colorado Water Institute

For more information email: **MaryLou.Smith@colostate.edu**

To register: **http://cdrassociates.org/training-opportunities/**

CDR Associates
Collaborative Decision Resources

POUDRE River Forum

The Poudre Runs Through It

Cultivating Connections for a Healthy, Working River

Third Annual Poudre River Forum

Friday, February 5, 2016

9am - 4pm | The Ranch, Loveland

Featuring

"Nexus of Agriculture and the Poudre River: Current Realities and Plans for the Future"

Representing a variety of agricultural operations and expertise, panelists discuss their reliance on Poudre River water, their planning for the future with a growing demand for this limited resource, and how the dynamics of this vital economic sector affect their relationship with the River.

Moderator: Luke Runyon, KUNC and Harvest Media

"An Inspiring Story of Agricultural/Environmental Cooperation on Wyoming's Little Snake River"

Keynote remarks from Pat O'Toole, Family Farm Alliance

"Challenges of Pursuing Water Projects and Initiatives: Key Ingredients and Lessons for Success"

Panelists explore getting to "yes" on large, complex and controversial projects. Examples include the Platte River Recovery Implementation Program, the Colorado River Cooperative Agreement, the Upper Colorado River Endangered Fish Recovery Program, and the Windy Gap Firming Project.

Moderator: Kevin Duggan, Coloradoan

Plus

Videos on the *Animated History of the Poudre* and *Year in the Life of Ditch Company*, two dozen educational displays, and a closing celebration with music from Blue Grama, Odell brews and other refreshments, and door prizes

$50

Scholarships and reduced rate are available.
Registration includes lunch and social hour.

Register online before JANUARY 25

http://cwi.colostate.edu/ThePoudreRunsThroughIt/forum_2016.shtml

Sponsored by The Poudre Runs Through It Study/Action Work Group - agricultural, urban, environmental, recreation and business interests collaborating to make the Poudre River "the world's best example of a healthy, working river."

Facilitated by Colorado Water Institute at Colorado State University.

For details, contact PoudreRiverForum@gmail.com

WATER RESOURCES
ARCHIVE

Colorado State University
MORGAN LIBRARY

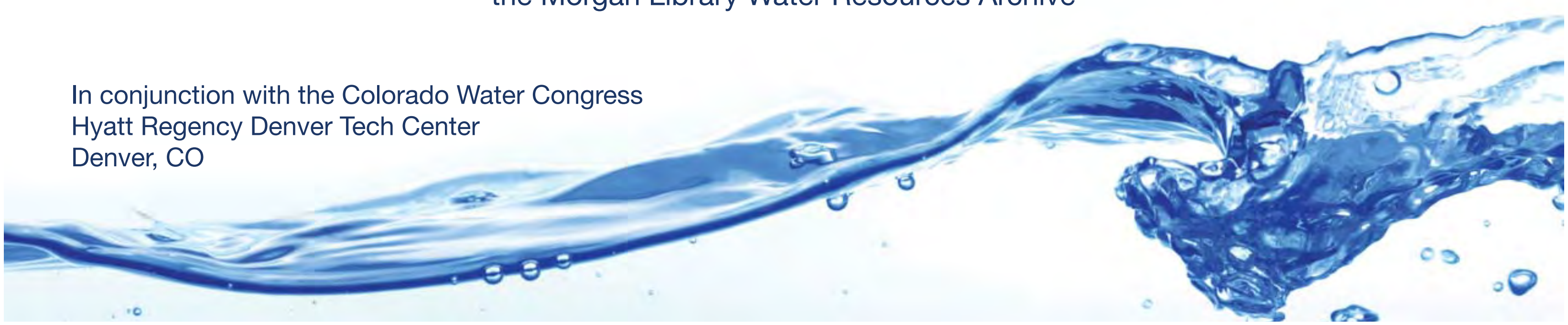
SAVE THE DATE

Thursday, January 28, 2016

Water Tables 2016

lib.colostate.edu/wt16

Reception, dinner and presentation to benefit
the Morgan Library Water Resources Archive



In conjunction with the Colorado Water Congress
Hyatt Regency Denver Tech Center
Denver, CO

Other Colorado Water Institute Research and Activity Reports

- The Ecological Benefits of Irrigated Agriculture and Potential Risks Under Changing Water Allocation/Supply, David Cooper, CWCB
- Data Collection and Analysis in Support of Improved Water Management in the Arkansas River Basin, Phase 2, Timothy K. Gates, CWCB
- Modeling the Influence of Conjunctive Water Use on Flow Regimes in the South Platte River Basin Using the South Platte Decision Support System Groundwater Flow Model – Year 2, Ryan Bailey, CWCB
- River Change and Flood Hazards on the Colorado Front Range, Brian Bledsoe, CWCB
- Alternatives to Permanent Fallowing Research Synthesis and Workshops, Bradley Hunt Udall, CWCB
- Evaluating the Time Series Discontinuity of the NRCS Snow Telemetry (SNOTEL) Temperature Data across Colorado, Steven Fassnacht, CWCB
- Determination of Consumptive Water Use of Winter Wheat in the Arkansas Valley, Allan Andales, CWCB
- Using Remote Sensing Assessments to Document Historical and Current Saved Consumptive Use (CU) on Alfalfa and Grass Hayfields Managed under Reduced and Full Irrigation Regimes: A New CU Documentation System, Perry Cabot, CWCB

TITLE: The ecological benefits of irrigated agriculture and potential risks under changing water allocation/supply

PRINCIPLE INVESTIGATORS:
Dr. David Cooper – Senior Research Scientist/Professor – Department of Forest and Rangeland Stewardship – Colorado State University – David.Cooper@colostate.edu
Erick Carlson – PhD student – Department of Forest and Rangeland Stewardship – Colorado State University – Erick.Carlson@colostate.edu

LOCATION: Larimer and Weld County, CO

PURPOSE OF THE RESEARCH:

NEED: Diversion of water from streams has a major effect on that stream's flow regime including altering the magnitude and duration of flooding events. The water is typically not consumed at the point of diversion, but flows through a system of canals and ditches to its point of use. These constructed canals account for significantly more length of flowing water than the natural channels in regions with irrigated agriculture. The novel riparian and aquatic habitats that have developed in and along canals contribute significantly to regional biodiversity. While there have been numerous studies of how changing the hydrologic regime of streams alters the in-channel and riparian processes and biota, little is known about how the hydrologic regime of canal networks influences its processes and biota. Canals must be investigated using the same scientific approaches as have been used for natural streams. This will help us better understand how aquatic and riparian biota may respond to changes in the flow regime of canals.

In agricultural regions, canal water is used to irrigate crops, and irrigation tailwater and/or runoff have created many wetlands. The benefits provided by these wetlands should be included in all ecological analyses. Wetlands in agricultural landscapes are thought to function in nutrient removal, and the need to remove nitrate before it reaches aquifers is critical. Reducing irrigation could impact local groundwater levels, shrinking or eliminating wetland functions adjacent to crop fields. Thus, understanding the functioning of wetlands in agricultural landscapes for both canal biotic communities and their geochemical processes is important for land and water managers.

PURPOSE: Information on the characteristics of aquatic and riparian ecosystems, their similarity to natural channels and floodplains and their position on the landscape will help regional water planners and conservationists quantify the impacts of potential water transfers and shortages on these biota. Irrigation supported wetlands will also be investigated to identify the physical and biotic components of the agricultural field & wetland system that facilitate the transformation of nitrate into nontoxic nitrogen compounds.

OBJECTIVES, METHODS, TIMELINE, AND COMPLETION DATE:

Canal Network Analysis

OBJECTIVES: A GIS model will be created to assign ecological benefit measures to segments of the canal network of four irrigation canals companies based on previously collected field data. Riparian and aquatic habitats biodiversity would be impacted under altered canal flows.

METHODS: Mapping software (ArcGIS 10x) will be used to create a spatially explicit network of canals with riparian and aquatic characteristics and water right priority as independent attributes. A spatially explicit model will be used to produce risk maps under several scenarios of water transfers and drought.

TIMELINE:

Fall 2014	- Riparian and aquatic condition data analyzed
Spring 2015	- Water transfer/shortage scenarios developed
Fall 2015	- Final scenarios run including wetland nitrate data - Final report compiled, findings presented to community

<u>Wetland Nitrate</u>

OBJECTIVES: To identify site conditions that lead to the highest rates of nitrate transformation and nitrate uptake by plants. Three farmers agreed to participate in the research in 2014 which led to the development of 4 crop sites in Weld County with diverse physical characteristics, irrigation method, and wetland vegetation.

METHODS:

Nitrate transformation: Experiments at the sites will determine the rate of denitrification. This research will identify the limiting factors in denitrification in the wetland using field experiments and laboratory analyses.

Plant uptake: The annual above ground biomass will be sampled for nitrogen content at the end of the growing season to measure the amount of nitrogen stored in leaves and stems as a proxy for nitrate uptake.

TIMELINE:

Fall 2014	- Identify additional sites to sample
Spring 2015	- Instrument sites, collect baseline data
Summer 2015	- Conduct field and laboratory experiments
Fall 2015	- Analyze results, present findings to community

Budget

Estimated Cost Per Year ($)	
Laboratory	2,900
Material and Supply	500
Equipment	2,400
PI Labor	20,160
Assistant Labor	5,760
Total	**31,720**

Budget Justification

Laboratory costs include the processing of gas samples from field experiments measuring *in situ* denitrification. Other lab costs include analyzing soil samples for carbon and microbial biomass. *Materials and supplies* include piezometer and groundwater well items and soil incubation chambers. *Equipment* includes automatic groundwater sensors and a soil temperature/pH probe. *PI labor* supports the PhD student lead for 7 months full time (Apr.-Oct.). *Assistant labor* supports an upper level undergraduate for 4 months during the summer sampling season (May-Aug.).

Pre-Proposal to Colorado Water Institute FY2015 Water Research Program

Title: Data Collection and Analysis in Support of Improved Water Management in the Arkansas River Basin, Phase 2

Principal Investigator: T. K. Gates, Prof. (tkg@engr.colostate.edu), **Co-Principal Investigator**: Jeffrey D. Niemann, Assoc. Prof.; *Civil and Environ. Engrg. Dept., CSU*

Location: Arkansas River Basin, Colorado

Purpose of the Research: The Arkansas River, drawing from Colorado's largest watershed (more than 28,000 mi^2), serves as a vital part of the State's water resource system. In the years to come, important decisions, including long-term investments in infrastructure and amended management practices, will need to be made in Colorado's Arkansas River Basin to enhance overall beneficial water use, redress serious problems of water quality degradation (e.g., salinity, selenium, uranium, and nutrients), conserve water, and find innovative ways (e.g., the Super Ditch) to address mounting pressures for increased diversions out of the Basin.

A reliable database is needed to allow characterization of the Basin's stream-aquifer system and to undergird both existing and future modeling tools, including the proposed Arkansas Basin Decision Support System (Ark DSS). Data on both surface and subsurface waters are needed in both the mountainous Upper Arkansas River Basin (UARB), above Pueblo Reservoir, and in the agriculturally-intensive Lower Arkansas River Basin (LARB). For over 15 years in the LARB and 3.5 years in the UARB, Colorado State University (CSU) has conducted extensive field monitoring to build such a database. *The project proposed herein constitutes the second phase of an on-going CWI FY2014 project (Phase 1). The purpose is to collect and analyze key field data in representative regions of the Arkansas River Basin needed to maintain and enhance a database in support of improved water management. Thereby, the project will prevent interruption of long-term data collection efforts.*

Objectives: The data-focused objectives of this one-year project are:

(1) Gather data on water table levels and water quality in existing groundwater monitoring wells distributed over representative study regions in the UARB and LARB, for characterization of the aquifer system and to support flow and solute transport models developed by CSU, the Lease-Fallowing Accounting Tool currently under development, and the proposed Ark DSS to be developed over the coming years by the Colorado Water Conservation Board;

(2) Gather data on water quality, water levels, and flows at selected sites along canals, tributaries, and the main stem of the Arkansas River in the UARB and LARB to characterize the stream system and to support current and future models;

(3) Conduct quality-control tests of the gathered data and enter them into the SQL database for the Arkansas River Basin developed and maintained by CSU; and

(4) Conduct a preliminary analysis of the data gathered under this project and summarize in a final report for use in system characterization and model support.

Methods: The cooperation of about 150 landowners with CSU provides access to sampling sites for water and related characteristics in the UARB and LARB. *Availability of these sites provides valuable in-kind matching support for this proposed project.* Data on groundwater and surface water quantity and quality have been gathered at numerous locations in Phase 1 in the UARB in July 2014 and in the LARB in August 2014 with additional sampling events planned for November 2014, January 2015, March

2015, and May 2015. In Phase 2, field data on water table depth and in-situ water quality parameters (electrical conductivity, temperature, pH, dissolved oxygen, and oxidation reduction potential) will continue to be gathered at about 20 existing groundwater monitoring wells in a study region in Chaffee County in the UARB and about 120 groundwater monitoring wells in two study regions within Otero, Bent, and Prowers Counties in the LARB. Three to four sampling events will be conducted in each of the three study regions. During two of the sampling events in both regions of the LARB, water samples will be extracted from a subset of about 50 wells and analyzed for major dissolved ions, nutrients, selenium, and uranium. Depending on water quality results from Phase 1, similar water samples may be taken from UARB wells during one sampling event. Water quality samples will be analyzed by EPA-approved laboratories. In-situ water quality parameters will be measured during the sampling events at about 24 surface-water sites in the UARB and at about 120 to 140 sites in the LARB. Flow rates will be measured at about 18 of the surface-water sampling sites in the UARB. Also, pressure transducers will be installed in stilling wells to monitor water level changes (hourly intervals) near flow-measurement locations within two or three key tributaries that are not equipped with permanent stream gauges.

Standard procedures and protocol will be followed in maintaining, cleaning, and calibrating wells, probes, pressure transducers, and pumping equipment for field measurements and sample collection. Field data will be checked to insure that values are physically reasonable and will be subjected to statistical outlier tests in comparison with data previously collected at the same locations.

Data will be added to CSU's SQL database (compatible with Colorado Division of Water Resources HYDROBASE). Preliminary data analysis will describe spatiotemporal variability of measured values and basic statistical characteristics in relation to previous data gathered in the study regions. Field measurement methods, along with procedures and results of preliminary analysis, will be documented in a final project report.

Timeline, & Completion Date: Data collection under Phase 2 is planned to commence in July 2015. Two irrigation season sampling trips and one to two off-season trips are planned for each of the study regions in the UARB and LARB. Data will be checked and entered into the database over the course of the one-year project. Final data analysis will commence on about 1 March 2016 and final report preparation will begin on about 15 June 2016. The project is scheduled for completion on 30 June 2016.

Budget: An estimated budget is summarized in Table 1.

Table 1. Estimated Budget ($) Project Budget (July 2015 – June 2016)

Salaries	17685
Travel	8893
Materials and Supplies	4000
Laboratory Analysis	12900
Indirect Costs (15%)	6522
TOTAL	50000

Budget Justification: Included are about 750 person-hours of undergraduate student effort and 0.5 person-months of faculty effort; mileage, per diem, and accommodations; parts/maintenance for multi-probes, pressure transducers, sampling pumps, acoustic Doppler velocimeters; monitoring well maintenance; water sample filters; sample bottles and preservatives; calibration solution; field books; and other miscellaneous supplies. Costs of laboratory analysis are based upon recent quotes from respective laboratories.

Modeling the Influence of Conjunctive Water Use on Flow Regimes in the South Platte River Basin Using the South Platte Decision Support System Groundwater Flow Model

Dr. Ryan Bailey, Assistant Professor, Department of Civil and Environmental Engineering, Colorado State University

Location of the Work: South Platte River Basin, Colorado

Background: The surface watershed of the South Platte River Basin (SPRB) lies on alluvial deposits that form an unconfined aquifer system connected with the surface water, with a thickness that reaches 200 ft in the lower SPRB. The aquifer, which sustains the base flow in the river, is recharged by infiltrations from precipitation and irrigation canals, as well as seepage from surface water bodies and streams. The SPRB constitutes a major source of water for eastern Colorado and has allowed agricultural growth to approach 1 million acres of irrigated cropland. Conjunctive use of surface and groundwater resources in the SPRB is regulated accordingly with the 1969 Groundwater Administration Act (Senate Bill 81), which requires all non-exempt groundwater rights to come into priority. Prior to 2003, about 9,000 groundwater irrigation wells were active in the SPRB (Nettles, 2011) with augmentation requirements of 5-10% of their water consumptive use to protect surface water rights. Following legislative changes that occurred in 2003-2004, water resources have been administered following strict priority rules since 2006, with all non-exempt wells required to have a decreed augmentation plan that replaces 100% of their estimated stream depletion. As a consequence of the increased cost for acquiring augmentation water, about 4,000 wells have been totally or partially curtailed from pumping during the last 6 years (Nettles, 2011), potentially resulting in reduced aquifer drainage and rising water table levels in several areas of the SPRB.

Purpose and Previous Results: The overarching goal of this project is to provide the Colorado Water Conservation Board (CWCB) with an independent evaluation of the SPDSS groundwater flow model, highlighting model capabilities, strengths, and weaknesses. The original project was carried out over a three-year period, and focused on the following tasks:

- Analysis of model grid/time discretization to provide general guidelines regarding spatial and temporal scales for which the SPDSS model seems most suited as a water management tool;
- Analysis of hydrogeological parameter distributions used in the model (hydraulic conductivity, aquifer storage properties, streambed conductance);
- Analysis of representativeness of hydrological stress data used in the model with respect to the SPRB hydrogeology;
- Analysis of model robustness and stability with respect to applying realistic aquifer stresses;
- Analysis of the effects of increased stream augmentation by aquifer recharge, changes in aquifer pumping based upon realistic estimates of the reduction in groundwater withdrawal, and hypothetical drought conditions; and
- Using the SPDSS model to estimate effect of aquifer stresses on streamflow depletion, and comparing with results from analytical models (i.e. Glover model).

The latter task is the focus of the FY14 (Year 3) project. The SPDSS model and the Glover model are being used to simulate the effects of pumping and recharge on streamflow depletion/accretion, with the streamflow depletion factor (Jenkins, 1968) used as a comparison metric. Based on current results, more work is needed to explore the effects over a range of realistic pumping/recharge rates, the methods used to calculate aquifer parameter values for the Glover model, and the reasons for differences between the SPDSS model and the Glover model.

Proposed Tasks for Year 4: The proposed tasks of the project for fiscal year 2015 are:

1. Continue comparing model results with analytical models currently used to assess the impact of aquifer stresses (well pumping, stream augmentation) on stream behavior;
2. Compare model results with results from local, "daughter" models in 1-2 locations within the SPRB

For Task 1, methods used during Year 3 of the project will be continued to: (1) Use the SPDSS groundwater flow model to assess impacts of well pumping and recharge ponds on stream depletion for a range of pumping/recharge rates; (2) Compare results with the Glover analytical model; and (3) Investigate reasons for differences.

For Task 2, 1-2 local-scale "daughter" models will be created from the SPDSS model, with model results (i.e. water table elevation, groundwater discharge to the stream network) compared against results from the regional-scale model. This will provide an indication of the accuracy of the regional-scale model and how model results from the SPDSS groundwater flow model can be translated to local conditions. It is anticipated that two daughter models will be created, with possible areas including the Sterling and LaSalle/Gilcrest areas. However, only one daughter may be created and used depending on the time and effort required for grid refinement, model calibration, etc…

Deliverables: At the end of year (June 30, 2016), a final technical report describing project activities, analysis results, and findings will be submitted to CWCB. In addition, the PI will meet with CWCB representatives at least twice during the project duration, either at the CSU campus or at CWCB offices to best coordinate projects activities and discuss project progress and future direction.

Completion Date: This project will be completed by June 30, 2016. All deliverables will be provided to the CWCB on or before that date.

Budget and Budget Justification:

0.75 Month Faculty Salary[1]	$9,656
12 Month PhD half-time Salary[2]	$27,694
1 semester tuition and fees	$5,462
Indirect Cost (15% rate)	$6,422
Total Cost for Fiscal Year	$49,234

[1]Includes 25% fringe

[2]Inclues 5.5% fringe

In addition to the Project Principal Investigator, Dr. Ryan Bailey, one PhD student will be involved and financially supported in this study. PhD student salary includes $1,700/month during the semester and $3,500/month during the summer.

River Change and Flood Hazards on the Colorado Front Range

Brian Bledsoe, Professor (brian.bledsoe@colostate.edu) & Joel Sholtes, PhD Candidate
Department of Civil and Environmental Engineering, Colorado State University

Location: Big Thompson & St. Vrain Basins. Tools, methodology applicable statewide.

Research Purpose: Nationally, nearly 25% of flood insurance claims come from areas outside of the 100 yr floodplain[1]. Flood-related impacts outside of the 100 yr floodplain were observed throughout the Colorado Front Range in spite of many September 2013 peak discharge estimates having magnitudes less than or equal to the 100 yr flood[1,2]. Observations of river change and the extent of flooding along the St. Vrain River near Lyons and Longmont, for example, demonstrate that dynamic river processes (river change) played an important role. River avulsion (channel acquiring a new route), erosion, and deposition processes during a flood all change the boundaries of the river and the floodplain leading to unexpected and unmitigated flood impacts. As recognized by Congress and FEMA in the 1994 National Flood Insurance Reform Act, ignoring river change during floods may in some cases underestimate hazards in the floodplain[3]. Existing methods for determining risk of river change are labor intensive and rely on historical aerial photograph coverage[4], largely lacking in Colorado, or are based on simplifications of geomorphic processes[5]. We propose to develop new methods to characterize the magnitude and frequency of river change within a river and floodplain corridor using information on flood hydraulics coupled with channel and floodplain geomorphic setting. Using available data in a GIS environment, this study will identify zones within a watershed that are more susceptible to change, and ultimately lead to planning tools and guidance tailored to the floodplain planning and management needs of state and local governments. It will compliment the “Channel Migration Zone” (CMZ) mapping effort underway for the 2013 flood response and watershed master plans.

Objectives & Methods: We hypothesize that two mechanisms working at different scales drive river change during floods: (1) excess stream power interacting with river bed and banks at the local scale, and (2) changes in down valley stream power due to breaks in slope and geomorphic context (valley width) at the river segment or watershed scale (e.g., canyon to prairie transition). The physical processes leading to river change at a given point are complex and chaotic; however, statistical models informed by physical measurements of flood impacts (bank retreat), hydraulic metrics (stream power), and geomorphic channel and valley classification have proven useful in identifying areas susceptible to river change[6,7,8]. Our objectives and methods are as follows: (1) Characterize the relationship between the magnitude of river change and the magnitude and frequency of the September 2013 flood event that caused it within each geomorphic class (valley width, slope, and river type). (2) Create multivariate logistic regression models that relate flood peak, stream power, and geomorphic class to the probability, type (e.g., lateral erosion, deposition, or avulsion), and severity of river change throughout a watershed. To our knowledge, a probabilistic approach to river change in the context of flood hazards has not previously been proposed. This objective will also provide an understanding of the qualitative relationships between the geomorphic setting of the river and floodplain to the risk and type of river change as guidance for river corridor planning. (3) Map reach-scale probability of river change based on our findings as case studies of the method. We propose the following tasks:

Task 1: *Stakeholder Meetings* (Month 1): Insight and feedback from local and state floodplain managers is essential to inform the format and scale of the results from this study and ensure their usefulness for planning needs. We will conduct stakeholder meetings up front to understand managers' experience with river change and its impacts on flooding within their districts. We will explore their level of interest, needs, and capabilities regarding the use of proposed guidance and maps to aid in floodplain management. Outcomes: Better informed framework and deliverables.

Task 2: *Data acquisition* (Month 1): This study will incorporate pre- and post- September 2013 flood aerial photography, river surveys, and digital elevation models (DEMs) to characterize pre- and post- flood river form; occurrence, type, and extent of river change; classify river and valley geomorphic type; and, calculate stream power throughout selected watersheds. An attempt will be made to obtain historic flood extent and river change data as well. These spatial data will be used in conjunction with flood peak and duration data from USGS gages and state sources of peak discharges.

Task 3: *Data Analysis & Field Verification* (Months 2-8): Three main types of analyses are to be conducted along selected river segments within the study watersheds: 1) river and valley geomorphic classification, 2) river network stream power estimation using GIS models, and 3) magnitude and associated frequency of river change. These data will be used in qualitative and multivariate statistical models to aid in predicting the type and severity of river change. The location and degree of river change will be mapped and then related to estimates and return intervals of flood peaks. Some limited fieldwork will be needed to verify GIS assessments of river change, geomorphic classification, and determine extent of engineered limitations to river change. We will calibrate this model with data collected from headwaters to main stem reaches in the Big Thompson and St. Vrain watersheds, and validate it on reaches not used for calibration to test its robustness and transferability. Outcomes: River change driving and response variable GIS database, statistical and qualitative models.

Task 4: *Report Results & Guidance Development* (Months 9-12): We will tailor our technical report and guidance document to state and local end users. This guidance document will focus on the qualitative relationship between river change and river and valley geomorphic type, and provide case study maps of river change risk. We will coordinate developing this document with the ongoing state-level CMZ delineation effort so that it complements the methods and guidance developed therein. We will pursue peer-reviewed publication of findings and regional presentation opportunities. Outcomes: Guidance Document for River Change Hazard Assessment in the Floodplain

Budget Justification

Category	Quantity	Budget
Principal Investigator, Faculty	0.5 mos.	$ 8,750
Graduate Researcher	6.5 mos.	$ 34,000
Travel (Stakeholder Mtgs, Field Validation)	~ 1,000 miles	$ 600
Facilities and Administrative @ 15%		$ 6,503
Total		$ 49,853

References

[1] Gease, M. FEMA natural hazards specialist, quoted in Walker, R. (2014). Coming Home, a Calculation of Risk, Reward and Restitution in Flood Zones. Headwaters. Colorado Foundation for Water Education. p 23-27.

[2] Houck, K (2014). CDOT/CWCB Hydrology Investigation, Phase One – 2013 Flood Peak Flow Determinations. CWCB Watershed and Flood Protection Section, 8p.

[3] National Flood Insurance Reform Act (1994). 42 U.S.C. § 577

[4] State of Washington, Department of Ecology. Channel Migration Assessment Program. http://www.ecy.wa.gov/programs/sea/sma/cma/index.html. Accessed October 8, 2014.

[5] Kline, M. and K. Dolan (2008).Vermont Agency of Natural Resources River Corridor Protection Guide. Fluvial Geomorphic-Based Methodology to Reduce Flood Hazards and Protect Water Quality. Vermont Agency of Natural Resources River Management Program. 25p.

[6] Bledsoe, B. P., & Watson, C. C. (2001). Logistic analysis of channel pattern thresholds: meandering, braiding, and incising. Geomorphology, 38(3), 281-300.

[7] Bizzi, S., & Lerner, D. N. (2013). The use of stream power as an indicator of channel sensitivity to erosion and deposition processes. *River Research and Applications*.

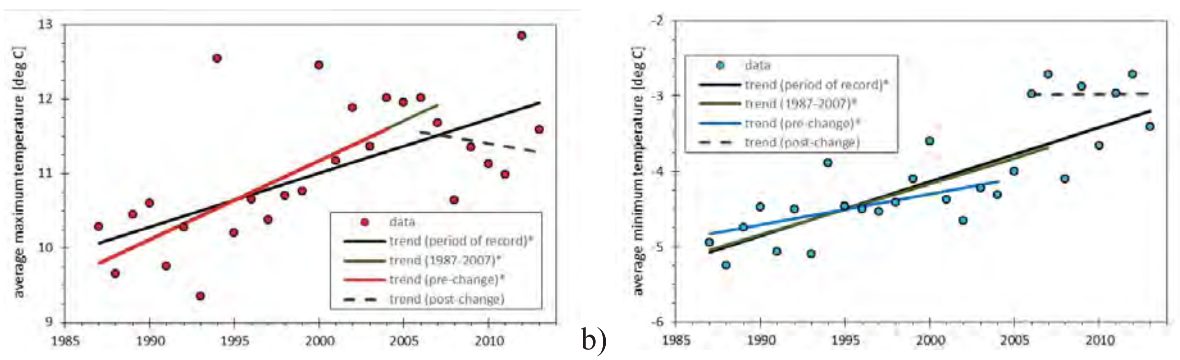
[8] Buraas, E. M., Renshaw, C. E., Magilligan, F. J., & Dade, W. B. (2014). Impact of reach geometry on stream channel sensitivity to extreme floods. *Earth Surface Processes and Landforms*.

1. Title: Evaluating the Time Series Discontinuity of the NRCS Snow Telemetry (SNOTEL) Temperature Data across Colorado

2. Principal Investigator: Steven R. Fassnacht, Professor of Watershed Science, Department of Ecosystem Science and Sustainability, Colorado State University, Fort Collins, <Steven.Fassnacht@colostate.edu>

3. Location: Fort Collins and some mountain areas in Colorado (NRCS SNOTEL stations)

4. Purpose of the research: Several recent studies (e.g., Clow, 2010; Harpold *et al*., 2012) have illustrated a very strong rate of warming in the mountains of Colorado based on trends from SNOTEL stations. For example, Clow (2010) found warming in January and July of 10 to 20 degrees per century at these sites since the 1990s. However, the temperature sensors have been moved at all the sites in the mid-2000s. Preliminary results show that there is a discontinuity in the temperature time series (e.g., Figure 1). As many water resources managers are beginning to use climate change information in their future planning, it is crucial to have a homogeneous time series of temperature data for higher elevation locations across Colorado. Such a dataset would also be useful for research, including hydrologic and climate modeling.



a) b)

Figure 1. Trends in the mean annual a) maximum and b) minimum temperature time series for four time periods at the Stillwater Creek SNOTEL station in Northern Colorado. Significant trends at the 5% confidence level are shown with solid line, while non-significant trends are shown with a dashed line.

5A. Objectives: The objectives of the proposed work are as follows: 1) assess the continuity of the daily maximum, average and minimum temperature time series, 2) correct the heterogeneity of the time series, and 3) determine the temperatures trends from the corrected datasets.

5B. Methods:

Most of the investigation will focus on analyzing the daily time series of daily maximum, average and minimum temperature at each station. All the data will be quality controlled (QC) to identify and flag erroneous measurements and other anomalies. The metadata will be used for each station to identify the data of initial installation and any changes to the temperature sensor. Trend significance (Mann-Kendall test; Gilbert, 1987), rate of change (Sen's slope; Gilbert, 1987), and a change point analysis (Pettitt, 1979) will be performed.

The NRCS Lakewood Snow Survey field office is taking hemispherical photographs above each snow pillow, and we have requested that photographs also be taken above each instrumentation hut. We will evaluate difference among these photographs to assess station (sensor) exposure (Fall *et al*., 2011). In consultation with the NRCS Lakewood office, stand-alone temperature sensors will be installed around several SNOTEL stations.

Where necessary and possible, the SNOTEL temperature time series will be adjusted; any adjustment will likely be performed to the pre-change time series as data will continued to be collected at the current, post-change position. Trend analysis will be performed on the new time series.

5C. Timeline:
Time Series Analysis – January 2015 through August 2015 (data and metadata retrieval and archiving, trend and change point analysis)
Field Evaluation – May 2015 through August 2016 (photograph analysis, stand-alone temperature sensor installation, data retrieval and processing)
Time Series Evaluation – May 2015 through October 2016 (time series adjustment, dataset archiving through CSU libraries and possibly NRCS, revised trend analysis)
Final Reporting – May 2016 through December 2016 (create revised time series metadata, write final report, write and submit journal manuscript)

5D. Completion Date: We anticipate this project being completed by the end of 2016.

6-7. Budget and Justification: TOTAL of $40,000
An undergraduate student (Amanda Weber) will perform most of the work, under the supervision of the principal investigator. Weber will be paid at a rate of $10 per hour for 20 hours per week for three semesters (spring 2015, fall 2015, spring 2016: $10,800), and for 40 hours per week for two summers (2015 and 2016: $9,600). The fringe at 1% is $204. PI Fassnacht will be paid for ½ month summer salary for each summer (2015 and 2016: $9,410) including fringe at 27.3% ($2,569). Travel expenses for additional sensor installation will be approximately 250 miles for 10 trips at $0.50 per mile. Twelve I-buttons and 24 funnels sensors will be purchased for $500. Various other miscellaneous supplies will also be purchased for $450, including batteries. The direct cost is $34,783, and an indirect cost of 15% is included on this proposal ($5,217).

Project No.

Andales: Lysimeter

PROJECT TITLE: Determination of Consumptive Water Use of Winter Wheat in the Arkansas Valley

PRINCIPAL INVESTIGATORS:

Dr. Allan A. Andales, Associate Professor of Irrigation and Water Science; Department of Soil and Crop Sciences, Colorado State University; Tel. (970) 491-6516;
Email: Allan.Andales@colostate.edu

Dr. Michael E. Bartolo, Research Scientist; CSU-Arkansas Valley Research Center, Rocky Ford, CO;
Tel. (719) 254-6312; Email: Michael.Bartolo@colostate.edu

Mr. Lane Simmons, Research Associate; CSU-Arkansas Valley Research Center; Rocky Ford, CO;
Tel. (719) 254-6312; Email: Lane.Simmons@colostate.edu

LOCATION WHERE THE WORK IS TO BE CONDUCTED: This project will be conducted at the Colorado State University (CSU) – Arkansas Valley Research Center (AVRC), Rocky Ford, CO.

PURPOSE OF THE RESEARCH

This proposal addresses priority research topic #5: "Develop new crop water use information for Colorado". One of the recommendations that came out of the Kansas v. Colorado Arkansas River Compact litigation is for Colorado to use the American Society of Civil Engineers (ASCE) Standardized Penman-Monteith equation (PME) to estimate crop evapotranspiration (ET) in the Arkansas River Basin. This equation requires accurate measurements of hourly weather data (solar radiation, air temperature, humidity, and wind speed) to calculate a reference crop ET (ET_r), which is a measure of local atmospheric demand for water. Crop ET (ET_c) is then calculated by multiplying ET_r by a crop coefficient (K_c) that varies with crop growth and development. This project will continue the long-term research to date, to more accurately calculate the ET_c of major irrigated crops in the basin, by defining the crop coefficients (K_c) used to convert ET_r to ET_c values and by validating (ground-truthing) the ET_r values calculated by the ASCE-PME for local conditions in the Arkansas River Basin. After alfalfa hay and corn, winter wheat is the next dominant irrigated crop in the basin and a localized K_c curve for it has not been developed. Therefore, a full growing season (2015-2016) of winter wheat ET_c data will be collected using the large (crop) lysimeter. The more accurate calculations of ET_c will ultimately improve the estimates of river flow that are used to determine compliance with the Arkansas River Compact. Related to this, accurate hourly weather data from 12 automatic weather stations in the basin are continuously needed to calculate ET_r and ET_c for the entire basin. These weather stations are part of the Colorado Agricultural Meteorological Network (CoAgMet). This work will also capitalize on the progress to date in validating calculated ET_r from ASCE-PME with measured alfalfa ET_r from the reference (small) lysimeter.

OBJECTIVES and METHODS

1. Develop a seasonal crop coefficient curve for winter wheat that accounts for local environmental conditions in the Arkansas basin.
2. Assess the impact of local weather and soil conditions on the ET_c of winter wheat at various growth phases of the crop.

The objectives will be achieved in close collaboration with engineers in the Colorado Division of Water Resources (CDWR). Oats will be planted on the large lysimeter in spring 2015 as a transition crop, after which winter wheat will be planted in fall 2015. Winter wheat ET_c from the large lysimeter and alfalfa ET_c from the reference lysimeter will be calculated by mass balance (from automated weighing scale readings) and aggregated to 5-minute, 15-minute, and hourly totals. Lane Simmons (Research Associate) will manage the daily operations, crop management, maintenance, and data quality control of the 2 lysimeters. The following will be the major deliverables of the project: (1) Seasonal crop coefficient curve that characterizes winter wheat ET_c (2015-2016 growing season) at different developmental phases; and is appropriate for local conditions in the Arkansas Basin; (2) Observed seasonal consumptive water use (ET_c) of winter wheat (2015-2016); (3) Accurate hourly weather data from 12 CoAgMet stations in the basin, made available through the CoAgMet online database; (4) One technical report published by the Colorado Water Institute detailing the methods and findings of the CSU research team. A draft of the report shall be provided to CDWR and CWCB by October 15, 2016.

This project will be conducted from July 1, 2015 to June 30, 2016.

BUDGET AND JUSTIFICATION

This agreement is for a maximum of $49,632 budgeted as follows.

Salary (one research associate; $5367/mo x 6.4 mo)	$34,347
Fringe benefits (@ 25.65%)	$ 8,811
Subtotal	$43,158
Indirect cost (@ 15%)	$ 6,474
Total	$49,632

These funds will pay for 6.4 months of work by one full-time research associate (Lane Simmons), who will manage the day-to-day operation of the lysimeters, take all measurements, and process the data.

Title: Using remote sensing assessments to document historical and current saved consumptive use (CU) on alfalfa and grass hayfields managed under reduced and full irrigation regimes: A new CU documentation system

Principal Investigator: Perry E. Cabot, Research Scientist, Colorado Water Institute and CSU Extension, Colorado State University,

Email: perry.cabot@colostate.edu

Location of research: Mesa, Delta, Montrose and Gunnison Counties

Purpose of the research

This project will address the research priority focused on developing new crop water use information for Colorado, by using remote sensing (RS) assessments of evapotranspiration (ET) rates in the Grand Valley and Uncompaghre River watershed. The proposed research will integrate with current field studies funded through the Colorado Water Conservation Board (CWCB) aimed at evaluating the water bank concept, which would work with agricultural water users to implement voluntary, compensated, interruptible supply agreements, thereby making water available on a temporary basis to address either Lake Powell or Colorado River Compact issues. Research ongoing on the Western Slope is aimed at measuring water balances on alfalfa and grass hayfields, for the purpose of calculating the saved consumptive use (CU) water achievable through reduced irrigation. Partial-season irrigation (also referred to as “split-season” irrigation) is the primary practice under evaluation. Funding has already been sought and is likely to be secured for the field instrumentation systems that will locally measure water balances. A water bank will require broad administration, however, in order to monitor the amount of saved CU from irrigation reductions on within a geographically diffuse array of individual fields. The proposed research is also congruent with numerous recommendations set forth in the URS (2013) report entitled *Assessing Agricultural Consumptive Use in the Upper Colorado River Basin*, pertaining to investigating “alternate methods for estimating actual CU where diversion records do not exist, specifically remote sensing data methods.”

Objectives, methods, timeline, completion date

Objectives. Towards the goal of developing a broad administrative approach for assessing water conservation, the proposed project will: 1) compare RS estimates of crop consumptive use against crop water budgets measured on alfalfa and grass hay/pasture managed by partial-season irrigation; 2) apply ET estimation models to archived imagery (estimated to exist for the past 20-25 years) to estimate historic CU on alfalfa and grass hay/pasture, in particular for fields at higher elevations, and; 3) compare modeled RS estimates of crop ET against CU estimates derived from measured diversion records, akin to methodology currently used in Colorado.

Methods. Partial-season irrigation regimes for grass pasture and alfalfa fields are being established at several Western Slope research sites to monitor multiple seasons of actual crop water use (ETa). The sites consist of plots ranging from 10-30 acres and are comprised of reference fields and additional fields where irrigation reductions will be imposed under the assistance of farmer-cooperators. Digital satellite imagery and RS (ERDAS Imagine Version 2014; 16-day frequency LANDSAT 8 and/or ASTER) will be used to estimate CU and ETa rates from reference versus treatment fields. Spatial and temporal calculation of ETa will couple peer-reviewed ET models (RESET; METRIC) ground-based soil water budgets. Additional CU comparisons will be made against baseline information from predicted values, historical assessments, and past records. Thermal band data will be "sharpened" to a higher spatial resolution by applying appropriate algorithms to correlate physical relationships between surface temperature and vegetative cover, using the higher resolution visible and near-infrared band data. Because temporal resolution of multispectral satellite images is too coarse (e.g., every 16 days for LANDSAT 8, or less if clouds are present in the scene) to estimate daily crop ET, this project will integrate the small unmanned aircraft system (sUAS) research currently funded through CWI to further intensify the spatial resolution of the ET model.

A graduate research assistant (GRA) will be employed to conduct the operational aspects of the research. The GRA will be supervised jointly by Dr. Cabot (PI) and Prof. Chávez. Dr. Cabot will take the lead on supervising research activities on the project sites and Prof. Chávez will direct the GRA in remote sensing, ET modeling methods and sUAS techniques. The GRA will be expected to relocate to Grand Junction during the summer 2015, where is provided at the CSU Agricultural Experiment Station. The different research locations are: a) furrow-irrigated alfalfa fields managed by a producer in the Grand Valley Water Users Association near Loma, CO; b) furrow-irrigated alfalfa fields managed by a producer in the Uncompaghre Valley Water Users Association near Delta, CO; c) flood-irrigated irrigated pasture fields managed by the Western Rivers Conservancy near Cimarron, CO. On each of these fields, it is expected that CWCB funding for in-field monitoring will be available under the CWCB water bank research. Additional assistance will be procured through AMEC consultants (funded by the Water Bank Workgroup) to gather historic data on diversion records for the study areas.

Timeline and Completion Date. It is proposed to start the project on 07/1/2015 and be completed by 06/30/2015. May/June: recruitment of GRA; July/August/September: data acquisition and analysis of field water budget data; October, November: ET model development, evaluation, comparison with historic records; December, January, February: research article production; March/April/May/June 2015: additional monitoring; June 2015: reporting to CWI.

Budget

Description	*Salary*	*Fringe*	*Total*
GRA	$21,600	$1,073	$22,673
Academic Faculty	$2,650	$613	$3,263
In-State Tuition for GRA:			$9,075
Travel Costs:			$2,517
Equipment (UAV battery pack, software license, computing hardware):			$5,950
TOTAL DIRECT COSTS:			$43,478
Facilities & Administrative: 15% TDC:			$6,522
TOTAL Project Request:			**$50,000**

Budget Justification. Funds are requested to: a) cover the salary/fringe ($22,673) of a graduate research assistant for 12 months; b) pay for in-state tuition credits ($9,075); c) cover salary/fringe for collaborator Chávez ¼-summer salary/fringe ($3,323); d) funding to support UAV flights, software/hardware to develop crop CU/ET ($6,600); e) travel ($2,517), and; IDC ($6,522). Total amount requested is $50,000 for one year.

USGS Summer Intern Program

Basic Information

Start Date:	3/1/2015
End Date:	2/29/2016
Sponsor:	DOI-USGS-Geological Survey
Mentors:	Robert S Regan
Students:	Ryan Logan

Internship Evaluation

Question	Score
Utilization of your knowledge and experience	Very Good
Technical interaction with USGS scientists	Good
Treatment by USGS as member of a team	Very Good
Exposure and access to scientific equipment	Very Good
Learning Experience	Good
Travel	About Right
Field Experience Provided	About Right
Overall Rating	A

Additional Remarks

The USGS Scientists are knowledgeable, approachable, and genuinely care about me and the project.

Basic Information

Start Date:	3/1/2015
End Date:	2/29/2016
Sponsor:	DOI-USGS-Geological Survey
Mentors:	Roland Viger
Students:	Melissa Valentin

Internship Evaluation

Question	Score
Utilization of your knowledge and experience	Very Good
Technical interaction with USGS scientists	Very Good
Treatment by USGS as member of a team	Very Good
Exposure and access to scientific equipment	Very Good
Learning Experience	Very Good
Travel	About Right
Field Experience Provided	About Right
Overall Rating	A+

Additional Remarks

My internship with the USGS MoWS group is an extraordinary opportunity to gain technical skills and professional experience while participating in meaningful research.

Basic Information

Start Date:	3/1/2015
End Date:	2/29/2016
Sponsor:	DOI-USGS-Geological Survey
Mentors:	Allen C Gellis
Students:	Lucas Nibert

Internship Evaluation

Question	Score
Utilization of your knowledge and experience	Acceptable
Technical interaction with USGS scientists	Acceptable
Treatment by USGS as member of a team	Acceptable
Exposure and access to scientific equipment	Acceptable
Learning Experience	Acceptable
Travel	About Right
Field Experience Provided	About Right
Overall Rating	A

Additional Remarks

Basic Information

Start Date:	3/1/2015
End Date:	2/29/2016
Sponsor:	DOI-USGS-Geological Survey
Mentors:	Robert S Regan
Students:	Samuel Saxe

Internship Evaluation

Question	Score
Utilization of your knowledge and experience	Very Good
Technical interaction with USGS scientists	Very Good
Treatment by USGS as member of a team	Very Good
Exposure and access to scientific equipment	Acceptable
Learning Experience	Very Good
Travel	About Right
Field Experience Provided	About Right
Overall Rating	A

Additional Remarks

None

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	16	0	1	0	17
Masters	4	0	2	0	6
Ph.D.	2	1	1	1	5
Post-Doc.	0	0	0	0	0
Total	22	1	4	1	28

Notable Awards and Achievements

Upper Yampa Water Conservancy District Scholarships Announced

The Upper Yampa Water Conservancy District John Fetcher Scholarship provides financial assistance to a committed and talented student who is pursuing a water-related career in any major at a public university within the state of Colorado. Congratulations to this year's recipient, Josie Rossi.

Josie is currently studying Mechanical Engineering through the Colorado Mesa University/University of Colorado Boulder partnership program with a minor in Watershed Science. She intends to pursue a water related career and would like to end up in the Yampa valley working as a water resource engineer on dams or irrigation systems.

Four States Irrigation Council Scholarship

The Four States Irrigation Council is a collaborative forum for the discussion of interstate-related issues and problems and the exploration of these. The Four States Irrigation Council awarded a $2,000 scholarship for the 2015-2016 academic year to one recipient interested in a career in irrigation or water-related fields and enrolled at a university or college in Colorado, Kansas, Nebraska, and Wyoming. The recipient, Carter Stoudt, is a student in Colorado State University's Department of Agricultural and Resource Economics. Carter would like to increase water efficiency in the agricultural industry.

2011CO245G – Year 1 and 2 – Water Quality Impacts of the Mountain Pine Beetle Infestation in the Rocky Mountain West

Presented research at 4 conferences.

Second Place for Poster Presentation at 2016 WE2ST Research Symposium.

Identified the need for more rigorous spatial and temporal groundwater level data.

Evaluated the use of GRACE over small scaled basin (South Platte) for aiding in the understanding of groundwater resources.

Advanced the knowledge and understanding of groundwater resources within the South Platte Basin.

Publications from Prior Years

1. 2014CO297B ("WOOD: Windows Of Opportunity for Debris Retention in Response to 2013 Front Range Flooding") - Articles in Refereed Scientific Journals - Wohl, E.; B. Bledsoe; K.D. Fausch; N. Kramer Anderson’ K. Bestgen; M. Gooseff, 2016,Management of large wood in streams: an overview and proposed framework for hazard evaluation, Journal of the American Water Resource Association, 52(2), 315-335.
2. 2012CO260B ("Structural and Functional Controls of Tree Transpiration in Front Range Urban Forests") - Articles in Refereed Scientific Journals - Gage, E.;D. J. Cooper, 2015,The Influence of Land Cover, Vertical Structure, and Socioeconomic Factors on Outdoor Water Use in a Western US City, Water Resources Management, 29,3877-3890.
3. 2012CO267B ("Using Water Chemistry to Characterize the Connection between Alluvial Groundwater and Streamflow Water Under Augmentation at the Tamarack Ranch State Wildlife Area, Colorado") - Articles in Refereed Scientific Journals - Roudebush, J.; J.D. Stednick;M. Ronayne, 2015, Numerical modeling of baseflow response to managed groundwater recharge along the South Platte River, CO, inAmerican Water Resources Association Annual Meeting, Denver, CO. Roudebush, J.; M. Ronayne;J.D. Stednick, Stream-aquifer modeling to assess the retiming of flow in an alluvial river by artificial groundwater recharge, Submitted to Journal of Hydrology.
4. 2012CO267B ("Using Water Chemistry to Characterize the Connection between Alluvial Groundwater and Streamflow Water Under Augmentation at the Tamarack Ranch State Wildlife Area, Colorado") - Dissertations - Roudebush, J., 2013, Numerical modeling of streamflow accretion by conjunctive use at Tamarack Ranch State Wildlife Area, Colorado, “MS Dissertation” Watershed Science, Warner College of Natural Resources, Colorado State University, Fort Collins,CO.
5. 2012CO265B ("Thermal preference of age-0 stonecats (Noturus flavus): Are thermal water quality standards protective for this species?") - Articles in Refereed Scientific Journals - Herdrich, A. T.;C. A. Myrick,2014, Critical thermal maximum of 20°C-acclimated adult stonecats Noturus flavus,Prairie Naturalist, 46(2),101-103.
6. 2014CO302B ("Exploration of Morphometric Approaches for Estimating Snow Surface Roughness") - Other Publications - Kamin, D.J.; S.R. Fassnacht, 2015, Exploration of a Geometric Approach for Estimating Snow Surface Roughness,Colorado Water, 32(2), 14-15.
7. 2013CO290B ("Assessing the agronomic feasibility of partial and full season hay fallowing as part of a Western Slope Water Bank") - Dissertations - Jones, L., 2015, Agronomic Responses of Grass and Alfalfa Hayfields to No and Partial Season Irrigation as Part of a Western Slope Water Bank, “MS Dissertation”, Soil and Crop Sciences, College of Agricultural Sciences, Colorado State University, Fort Collins, CO.
8. 2011CO245G ("Water Quality Impacts of the Mountain Pine Beetle Infestation in the Rocky Mountain West: Heavy Metals and Disinfection Byproducts ") - Conference Proceedings - Ruybal, C.J.; Hogue, T.S.;McCray, J.E., 2015, Assessment of Groundwater Storage Changes and Recharge in the South Platte Basin, in American Water Resources Association Annual Water Resources Conference, Denver, CO.
9. 2011CO245G ("Water Quality Impacts of the Mountain Pine Beetle Infestation in the Rocky Mountain West: Heavy Metals and Disinfection Byproducts ") - Conference Proceedings - Ruybal, C.J; Hogue, T.S.;McCray, J.E., 2015, Spatiotemporal Assessment of Groundwater Resources in the South Platte Basin, Colorado, inAmerican Geophysical Union Fall Meeting, San Francisco, CA.
10. 2011CO245G ("Water Quality Impacts of the Mountain Pine Beetle Infestation in the Rocky Mountain West: Heavy Metals and Disinfection Byproducts ") - Conference Proceedings - Ruybal, C.J; Hogue, T.S.; McCray, J.E., 2016, Spatiotemporal Assessment of Groundwater Resources in the South Platte Basin, Colorado, in WEsST Research Symposium, Colorado School of Mines, Golden, CO.

11. 2011CO245G ("Water Quality Impacts of the Mountain Pine Beetle Infestation in the Rocky Mountain West: Heavy Metals and Disinfection Byproducts ") - Conference Proceedings - Ruybal, C.J.; Hogue, T.S.;McCray, J.E., 2016, Spatiotemporal Assessment of Groundwater Resources in the South Platte Basin, Colorado, in National Ground Water Association 2016 Groundwater Summit, Denver, CO.
12. 2014CO296B ("Ecological Functions of Irrigation Dependent Wetlands") - Conference Proceedings - Carlson, EA., 2015,Wetland capacity for nitrate transformation and uptake an irrigated agricultural landscape, in Colorado Sustaining Watersheds Conference, Avon, CO.
13. 2013CO290B ("Assessing the agronomic feasibility of partial and full season hay fallowing as part of a Western Slope Water Bank") - Conference Proceedings - Jones, L., 2015, Agronomic Responses of Grass and Alfalfa Hayfields to No and Partial Season Irrigation as Part of a Potential Colorado Western Slope Water Bank in American Water Resources Association (AWRA) Annual Water Resources Conference, Denver, CO.
14. 2014CO302B ("Exploration of Morphometric Approaches for Estimating Snow Surface Roughness") - Conference Proceedings - Kamin, D.;S.R. Fassnacht, 2015,New Approaches for Estimating Snow Surface Roughness, in American Geophysical Union Hydrology Days Conference, Fort Collins, CO.
15. 2014CO302B ("Exploration of Morphometric Approaches for Estimating Snow Surface Roughness") - Conference Proceedings - Kamin, D.;S.R. Fassnacht, 2015, New Approaches for Estimating Snow Surface Roughness, inWestern Snow Conference, Grass Valley, CA.
16. 2012CO262B ("Reconstructing a Water Balance for the San Luis Valley: Streamflow Variability, Change, and Extremes in a Snowmelt Dominated Internal Drainage Basin") - Conference Proceedings - Venable, N.B.H;, P.M. Brown;S.R. Fassnacht, 2013, Reconstructing Streamflow to Nowhere: Long-term Variability of Flow Into the San Luis Valley Closed Basin, Colorado, USA, in American Geophysical Union Hydrology Days Conference, Fort Collins, CO.
17. 2013CO290B ("Assessing the agronomic feasibility of partial and full season hay fallowing as part of a Western Slope Water Bank") - Conference Proceedings - Jones, L., 2015, Agronomic Responses to Partial and Full Season Fallowing of Alfalfa and Grass Hayfields, Water Bank Workgroup Meeting, Water Bank Working Group Meeting at the Colorado Water Congress, Vail, CO.